Volume 29 OCTOBER, 1945 Number 10

BULLETIN
of the
American Association *of* Petroleum Geologists

CONTENTS

BULLETIN

of the

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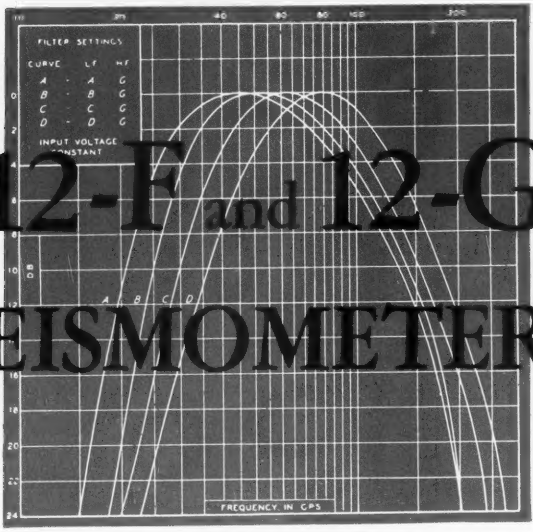

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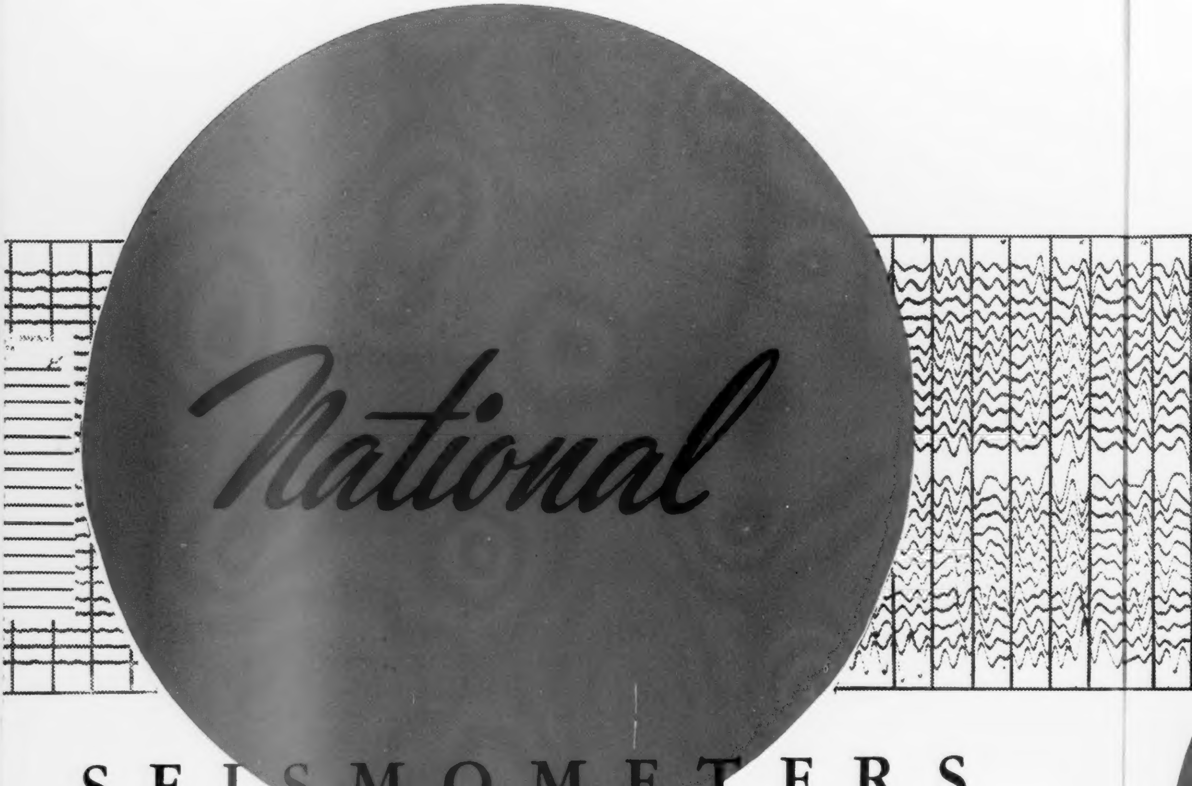

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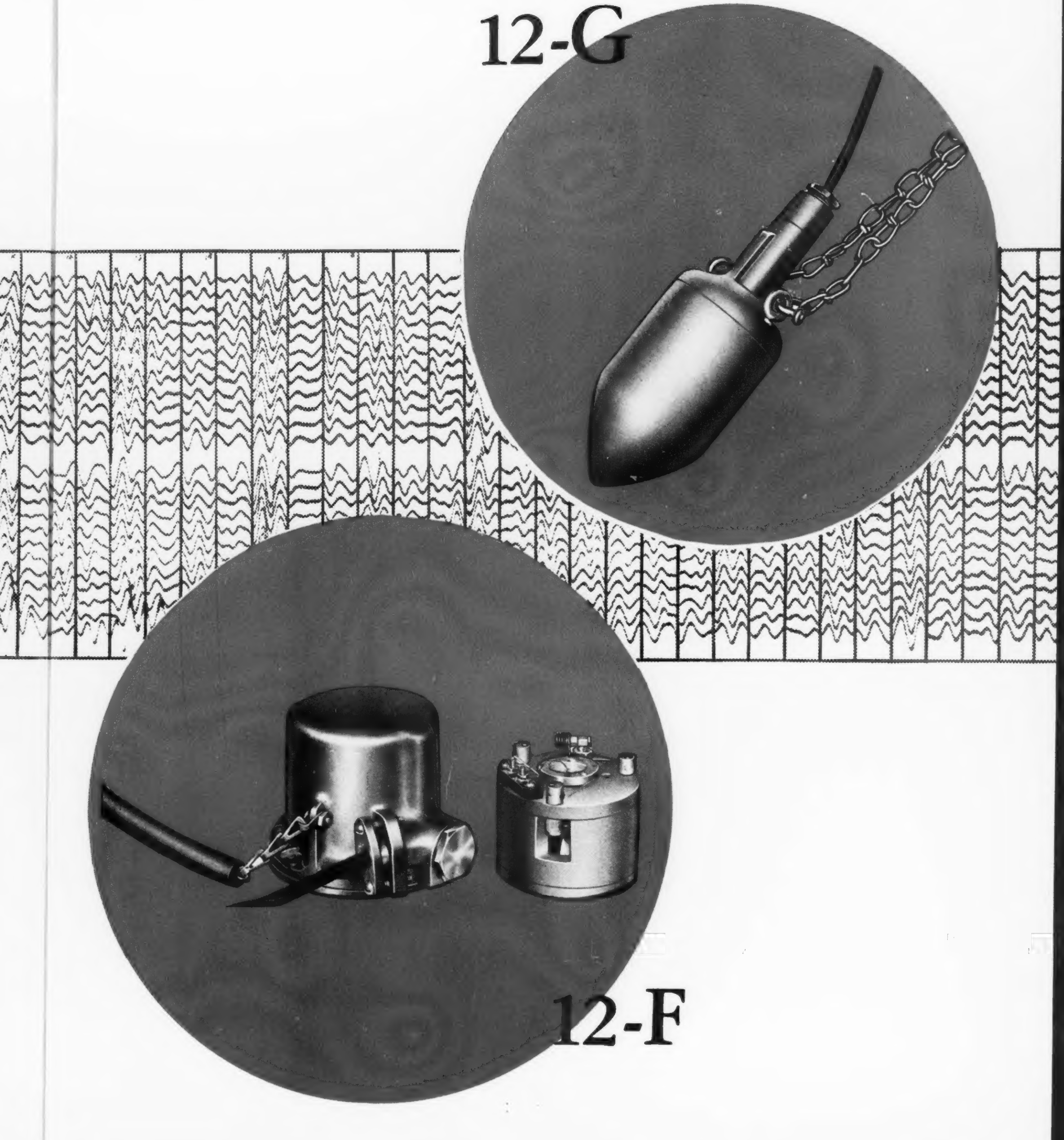

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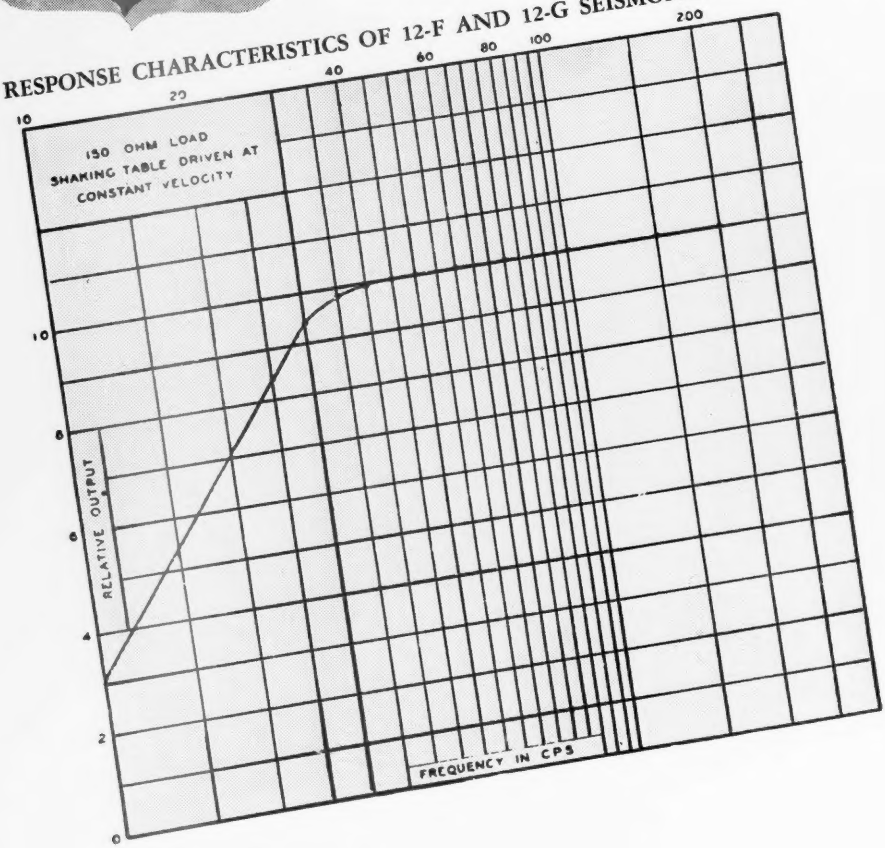

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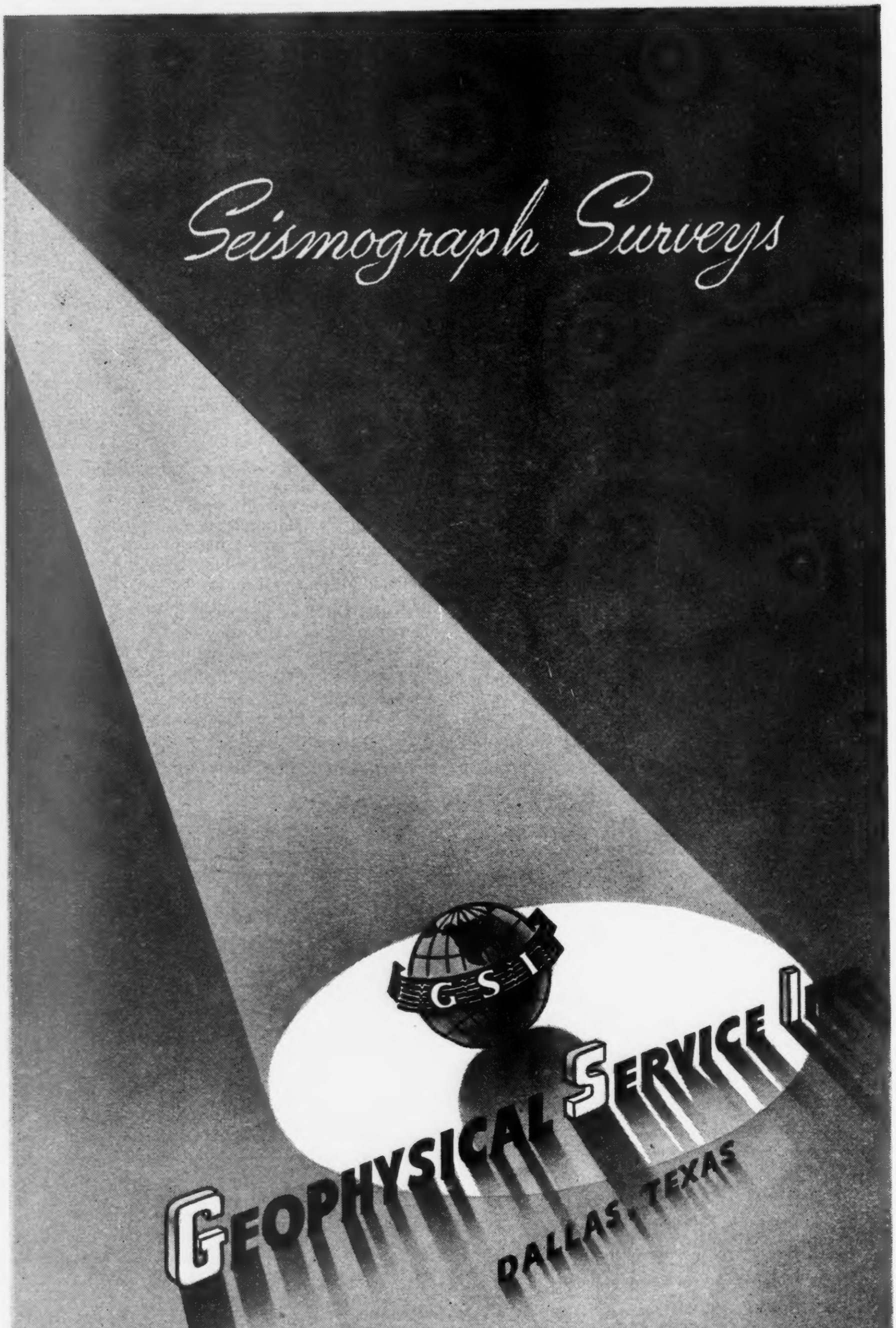
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OCTOBER, 1945

GEOLOGY OF OREGON AND WASHINGTON AND ITS RELATION TO OCCURRENCE OF OIL AND GAS[1]

CHARLES E. WEAVER[2]
Seattle, Washington

ABSTRACT

Oregon and Washington contain the following topographic provinces, each with distinctive geological features: Coast Range, Cascade Mountains, Puget Sound-Willamette trough, Okanogan Highlands, Blue Mountains, Klamath Mountains, Olympic Mountains, and Columbia Plateau. The northern Cascades of Washington, the Okanogan Highlands, the Klamath Mountains and a part of the Blue Mountains are composed largely of thick sections of folded Paleozoic and early Mesozoic marine sediments which have been intensely metamorphosed and deformed. Associated with these are granites and other intrusive rocks. The formations in eastern Oregon and Washington and in the Cascade Mountains constitute the base on which rests a thick series of Tertiary lavas and associated lacustrine and fluviatile sediments. The core of the Olympic Mountains consists of greatly indurated but not metamorphosed sedimentary rocks, possibly late Mesozoic in age, which are bordered on the north, east, and south by 3,000 feet of Eocene volcanics and about 8,000 feet of later Tertiary marine sediments. Granites are absent in this area. The Coast Range from the Olympic Mountains southward to the Klamath Mountains is composed entirely of folded and locally faulted Tertiary lavas and sediments ranging from 10,000 to 20,000 feet thick. The basement rocks are unknown but the lower part of the Tertiary section everywhere consists of 3,000 to 5,000 feet of basic volcanics largely submarine in origin.

Crustal movements of late Miocene age produced northwest-southeast folds in Washington, and north-south folds in the Coast Range of Oregon. Major north-south upwarps and downfolds at the close of the Pliocene were superimposed on the earlier structures with the resultant development of the Coast Range, Cascade Mountains, and the intervening trough.

Indications of oil in the form of very small seepages occur in the Tertiary formations west of the Cascade Mountains. There is no conclusive evidence that commercial amounts of oil are present in these formations although drilling tests under geologic control are considered warranted. The metamorphic rocks, granites, lavas and continental sediments in eastern Oregon and Washington, and in the northern Cascade Mountains are considered as being unfavorable for the commercial occurrence of oil.

The states of Oregon and Washington bordering the Pacific Ocean lie within an area of greatly diversified topography, climate, and vegetation with altitudes ranging from sea-level to more than 8,000 feet. The Coast Range and the Cascade Mountains constitute two nearly parallel north-and-south structural upwarps with an intervening downwarp represented by the Puget Sound Basin in Wash-

[1] Lecture delivered during January, 1945, before the affiliated societies of the American Association of Petroleum Geologists, under the auspices of the Association Distinguished Lecture Committee. Manuscript received, June 4, 1945.

[2] Department of geology, University of Washington.

ington and the Willamette Valley in Oregon. These topographic units extend southward into California as the Coast Range, the Sierra Nevada, and the Great Valley, the last being separated from the Willamette Valley by a structural knot containing the Siskiyou Mountains. Eastern Oregon and Washington are characterized by lava-covered plateaus whose surface, as the result of crustal warping, ranges in altitude from less than 1,000 feet to more than 5,000 feet. Within this territory there are mountainous areas which have been uplifted locally to more than 9,000 feet. The crest of the Cascade Mountains causes a climatic differentiation with an average low rainfall on the east side and relatively high humidity on the west. This in turn has permitted the development of a semi-desert vegetation in eastern Oregon and Washington, and dense forests and undergrowth in the western parts of those states.

The major topographic features of Oregon and Washington may be grouped into eight definite units each of which possesses distinctive geologic characteristics. These may be defined as the Okanogan Highlands, the Columbia Plateau, the Blue Mountains, the Malheur Plateau, the Cascade Mountains, the Puget Sound-Willamette Valley Basin, the Klamath Mountains, and the Coast Range. Vancouver Island and the Olympic Mountains form an extremely rugged part of the Coast Range, and because of their more complex geologic character are described separately.

Okanogan Highlands

The Okanogan Highlands in northeast Washington extend from the Cascade Mountains eastward to Idaho, and from the Canadian boundary southward to the Columbia Plateau. They include the southern continuation of the Columbia and Selkirk ranges of British Columbia, and the western part of the Coeur d'Alene Mountains of Idaho. These mountains, which have been structurally deformed, have altitudes of more than 6,000 feet near the Canadian line with a gradual decrease southward to 2,300 feet along the east-west course of the Columbia River. The surface has been deeply dissected by several southward-flowing streams, the largest of which is the Columbia River.

The areal geology of this region is fairly well known and some parts have been mapped in considerable detail. Approximately 50 per cent of the surface exposures consist of granites and other associated intrusive rocks; the remainder is composed of metamorphic rocks largely Paleozoic and early Mesozoic in age. Residual irregular-shaped patches of lavas, tuffs, and continental sediments of Tertiary age rest unconformably on the eroded and beveled edges of these older greatly folded and otherwise deformed rocks. In Stevens County east of the north-south course of Columbia River there are exposed nearly 43,000 feet of metamorphosed sediments of Paleozoic age which consist of alternating formations of quartzite, crystalline limestone, schist, and greenstones.[3] The few fossils obtained

[3] C. E. Weaver, "The Mineral Resources of Stevens County," *Washington Geol. Survey Bull. 20* (1920), pp. 49–77.

indicate ages ranging from Cambrian to Carboniferous. These sediments accumulated upon a differentially subsiding floor of a part of the Paleozoic Cordilleran trough. Farther west in the Okanogan Highlands are non-metamorphosed but greatly indurated marine sediments possibly Jurassic and Cretaceous in age, although the fossils obtained are few in number and poorly preserved. Crustal disturbances probably late Mesozoic in age, accompanied by granitic invasions, produced intense metamorphism of the sediments together with compression and uplift. By Miocene time long continued erosion developed a surface possibly not far above sea-level, which may have been continuous with that beneath the lavas of the Columbia Plateau. The lavas of the plateau on the south formerly extended northward over a part of the surface of the Okanogan Highlands, and in certain places north of Spokane lacustrine and fluviatile sediments accumulated locally in temporary depressions. Late in the Tertiary the northeastern part of Washington was uplifted differentially, and so extensively eroded that only irregular-shaped residual patches of lava remained.

The sedimentary formations which have been grouped as the Stevens series originally consisted of sandstones, shales, and limestones. These have been closely compressed into anticlines and synclines with axes trending slightly east of north. It is possible that some of the shale or limestone beds at an earlier time may have existed as source beds for oil or gas, and that certain of the more porous sandstones may have acted as retaining beds. However, it seems probable that such accumulations would have been destroyed as the result of metamorphic action. The original mineral grains in the sandstone in part have been recrystallized and the interspaces largely filled as the result of crystal growth, thus greatly reducing the porosity of the quartzites. There was no possibility for the escape of the gases into the Tertiary lavas and tuffs since metamorphism and erosion occurred before their accumulation. The lavas may not be considered as a source for oil and gas, and the conditions accompanying the deposition of Tertiary continental sediments are ordinarily unfavorable. It is possible that small quantities of vegetable material may have been buried with the lacustrine and fluviatile sediments, but the quantity would be sufficient only for the local production of non-commercial amounts of marsh gas. The writer is not aware of oil seepages or important evidences of gas in any of the formations in the Okanogan Highlands.

Blue Mountains

The Blue Mountains separate the Columbia Plateau from the Malheur Plateau and extend from the northeast corner of Oregon S. 35° W. to the Cascade Mountains. The northeastern end, which also includes a part of southeastern Washington, attains an average altitude of 8,000 feet above sea-level with peaks here and there of nearly 10,000 feet. The altitudes gradually decrease to 4,000 feet where the mountains near the Cascades form a broad axial upwarp which merges into the lava plains of the Columbia Plateau in north-central Oregon and into the more highly elevated Malheur Plateau of southeastern Oregon. The

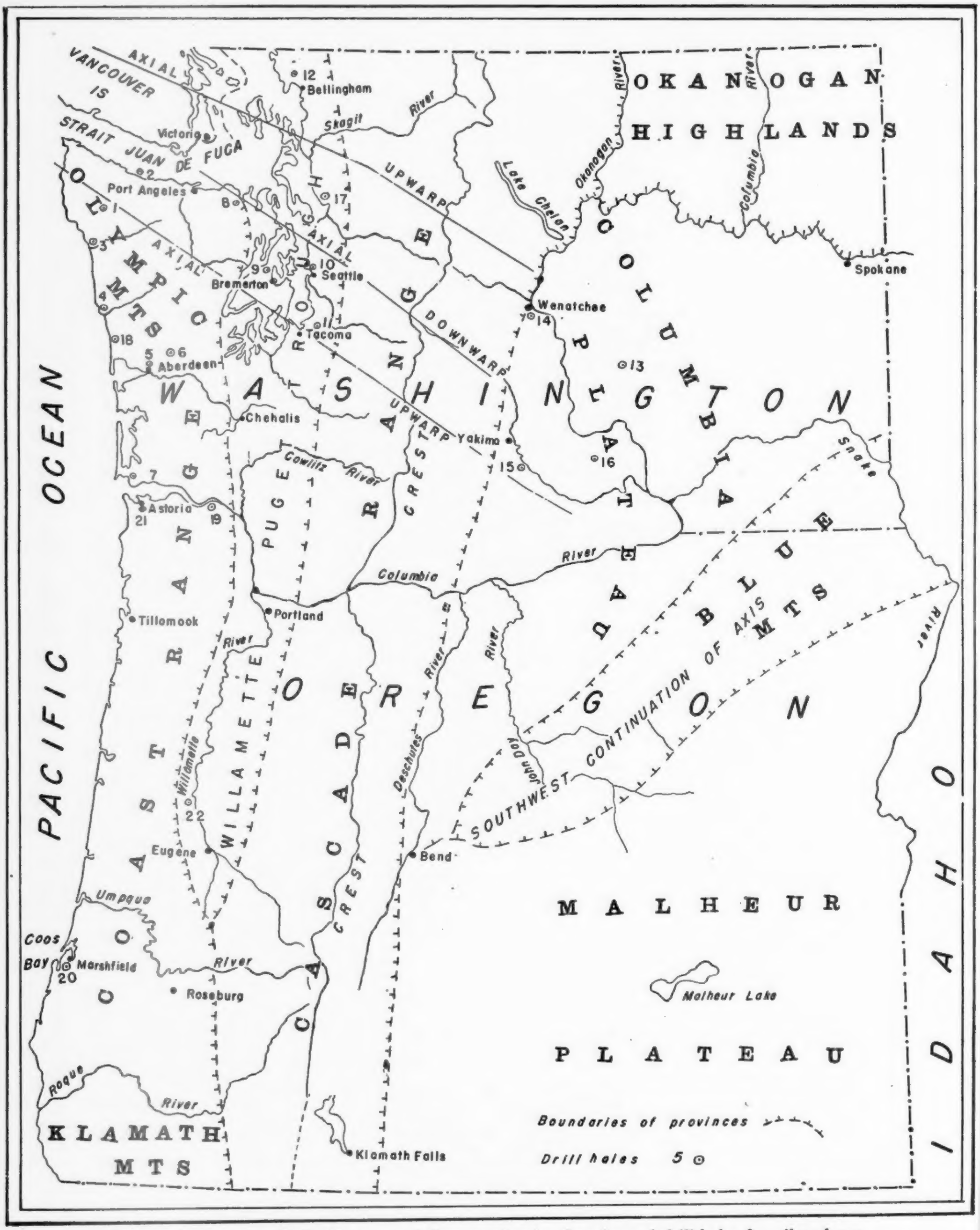

FIG. 1.—Index map of Washington and Oregon, showing locations of drill-holes for oil and gas. West-east width of area mapped, approximately 360 miles.

LOCATION OF DRILL HOLES FOR OIL AND GAS REFERRED TO ON INDEX MAP

Location Number	*Name of Well*	*Company*	*Date of Drilling*	*Depth in Feet*	*Remarks*
1	La Push	La Push Oil Co.	1902	600	3 miles SE. La Push, NE. $\frac{1}{4}$ Sec. 2, T. 28 N., R. 15 W.
	Washington	Washington Oil Co.	1912	2125	At Forks, SE. part Sec. 9, T. 28 N., R. 13 W.
	Forks 1	Forks Drilling Co.	1919	2300	Forks, SE. $\frac{1}{4}$ Sec. 9, T. 28 N., R. 13 W.
	Bogachiel 1	Sol Duc Oil Co.	1923	2225	5 miles SW. Forks, near center Sec. 22, T. 28 N., R. 14 W.
	Forks 2	Forks Drilling Co.	1924	1000–2000	Forks, SE. $\frac{1}{4}$ Sec. 9, T. 28 W., R. 13 W.
	Olympic 1	Mordello L. Vincent	1932	2940	Quillayute, 6 miles W. of Forks
	Rosalie 1	Forks Prairie Oil Co.	1932	2350	Forks, W. $\frac{1}{2}$, SE. $\frac{1}{4}$ Sec. 9, T. 28 N., R. 13 W.
	Bloedel-Rudding 1	Sun Oil Co.	1937	6210	Forks, NW. $\frac{1}{4}$ Sec. 4, T. 28 N., R. 13 W.
2	Pronounced odor of gas from sandy shale exposed on beach in Clallam County, Washington, near first point west of Gettysburg in SE. $\frac{1}{4}$ of Sec. 19, T. 31 N., R. 9 W.				
3	Hoh Head 1	Jefferson Oil Co.	1913	901	Near mouth Hoh River, SW. $\frac{1}{4}$, SE. $\frac{1}{4}$ Sec. 12, T. 2 N., R. 14 W.
	Hoh Head 2	Jefferson Oil Co.	1914	1108	Near mouth Hoh River, SW. $\frac{1}{4}$, SE. $\frac{1}{4}$ Sec. 12, T. 26 N., R. 14 W.
	Sims 1	Leslie Petroleum Co.	1931–1933	2067	Near mouth Hoh River, SE. cor., NW. $\frac{1}{4}$, SE. $\frac{1}{4}$ Sec. 12, T. 26 N., R. 14 W.
	Gilkie 1	Hoh River Oil Co.	1931	2155	Near mouth Hoh River, SE. cor., NW. $\frac{1}{4}$, SE. $\frac{1}{4}$ Sec. 12, T. 26 N., R. 14 W.
	Gilkie 2	Hoh River Oil and Gas Development Co.	1933	886	Near mouth Hoh River, SE. cor., NW. $\frac{1}{4}$, SE. $\frac{1}{4}$ Sec. 12, T. 26 N., R. 14 W.
	Kipling 1 (Gilkie 3)	Washington Oil Co., Ltd.—Consolidated Oil Co. of Washington, Inc.	1936	808	SE. cor. NW. $\frac{1}{4}$, SE. $\frac{1}{4}$ Sec. 12, T. 26 N., R. 14 W.
3	Kipling 2 (Gilkie 4)	Washington Oil Co.	1936	656	Near mouth Hoh River, 200–300 feet E. of Kipling 1
	Consolidated 2 (Gilkie 5)	Consolidated Oil Co. of Washington	1937	1070	Near mouth Hoh River, 160 feet S. of Kipling 1
	Churchill 1	Hoh River Oil Explor. Co.	1937	1600	Near mouth Hoh River, NW. cor., NE. $\frac{1}{4}$, SE. $\frac{1}{4}$ Sec. 12, T. 26 N., R. 14 W.
4	Quinault 1	Indian Oil Co.	1913	500	Near Tahola, NW. $\frac{1}{4}$ Sec. 35, T. 22 N., R. 13 W.
	Quinault 2	Indian Oil Co.	1914	840	Near Tahola, NW. $\frac{1}{4}$ Sec. 35, T. 22 N., R. 13 W.
5	A. Robinson 1	Ohio Oil Co.	1933	6725	Grays Harbor Co., Washington, near Aberdeen, Sec. 5, T. 17 N., R. 9 W.
6	Weyerhauser 1	Sharples Corp.	1944	1385	Grays Harbor Co., Sec. 31, T. 19 N., R. 8 W., 990 feet from E. line and 940 feet from S. line
	Weyerhauser 2	Sharples Corp.	1945	3200	Grays Harbor Co., Sec. 31, T. 19 N., R. 8 W., 330 feet from W. line and 270 feet from S. line

LOCATION OF DRILL HOLES FOR OIL AND GAS REFERRED TO ON INDEX MAP—*Continued*

Location Number	*Name of Well*	*Company*	*Date of Drilling*	*Depth in Feet*	*Remarks*
	Weyerhauser 3	Sharples Corp.	1945	3309	Grays Harbor Co., Sec. 31, T. 19 N., R. 8 W., 270 feet N. of S. line an 2170 feet W. of E. line
7	McGowan 1	Union Oil Co. of Calif.	1930	4380	N. side of mouth of Columbia River, Sec. 22, T. 9 N., R. 10 W.
8	Sequim	Sequim Oil Co.	1918	1400	Sequim, Clallam Co , Sec 30, T. 30 N., R. 3 W.
9	Name unknown	Kitsap Oil and Development Co. of Bremerton, Washington	1914	1408	Chico, Kitsap Co., Washington, Sec. 5, T. 24 N., R. 1 E.
10	Name unknown	Morris Oil Co.	1914	2600	At Ballard in Seattle
11	Flaming Geyser 1		?	2760	E. of Tacoma, Washington, Sec. 34, T. 21 N., R. 6 E.
	Bob 1	Unknown	?	3445	E. of Tacoma Washington, 300 feet W. and 330 feet N. of SE. cor., Sec. 36, T. 21 N., R. 6 E.
11	Kraupa 1	Sound Cities Oil and Gas Co.	1938	4878	East of Tacoma, Washington, 2000 feet W. and 1400 feet N. of SE. cor., Sec. 34, T. 21 N., R. 6 E.
	Kraupa 2	Panhandle Oil and Gas Co.	1942	6500	E. of Tacoma, 700 feet W. and 2000 feet N. of SE. cor., Sec. 36, T. 21 N., R. 6 E.
	Buckmann 1	Sharples Corporation	1944	4016	E. of Tacoma, 2640 feet S. of N. line and 380 feet E. of W. line of Sec. 36, T. 21 N., R. 6 E.
12	Enterprise	National Oil and Gas Co. of Vancouver, B. C.	1914	3615	Whatcom Co., Washington, SE. ¼, SE. ¼ Sec. 19, T. 39 N., R. 2 E.
	Lange 2	W. T. Lange	1931	2008	Whatcom Co., SE. ¼, NE. ¼ Sec. 28, T. 39 N., R. 2 E.
	Six shallow wells in Whatcom Co., Washington, Secs. 27 and 28, T. 39 N., R. 2 E., ranging in depth from 166 to 330 feet. Drilled in glacial material to contact with upturned edges of sandstones and shales of continental origin and probable early Eocene age. Gas produced for a short time, 1934 and 1935.				
	Name unknown	Pelican Petroleum Co.	1941	5500	Whatcom Co., SE. cor., SW. ¼ Sec. 32, T. 38 N., R. 3 E.
13		Peoples Oil and Gas Co.	1938	4550	Grant Co., Washington, NW. cor., Sec. 19, T. 17 N., R. 28 E. Entirely in basalt
14	Norco 1	Northwest Oil Research Corp.	1933–1942	4903	SW. of Wenatchee, Washington, Sec. 26, T. 22 N., R. 20 E.
15	Union Gap	Miocene Petroleum Co.	1936–1939	3810	SE. of Yakima Washington, Sec. 17, T. 12 N., R. 19 E.
16	Rattlesnake Hills area 18 miles northeast of Prosser, Benton Co., Washington. Fifteen wells drilled in Miocene basalt to depths ranging from 700 to 1300 feet with one 3600 feet. Gas production in 1936: 183,177,000 cubic feet with a reduction to 36,323,000 cubic feet in 1940. No production at present.				
17	Lake Goodwin 1	Puget Sound Oil Co.	1928	5959	Snohomish Co., Washington, NW. cor., NW. ¼, SE. ¼ Sec. 22, T. 31 N., R. 4 E.
17	Lake Goodwin 2	Puget Sound Oil Co.	1931	5959	Snohomish Co., Washington, 1320 feet N. and 1320 feet E. of SW. cor., Sec. 34, R. 31 N., R. 4 E.

LOCATION OF DRILL HOLES FOR OIL AND GAS REFERRED TO ON INDEX MAP—*Continued*

Location Number	*Name of Well*	*Company*	*Date of Drilling*	*Depth in Feet*	*Remarks*
	Name unknown	Solduc Oil Co.	1925	3282	Snohomish Co., N. of Monroe 1600 feet E. and 750 feet S. of NW. cor., Sec. 15, T. 28 N., R. 6 E.
	Name unknown	Florence Oil and Gas Co.	?	1160	Snohomish Co., SW. ¼ Sec. 8, T. 31 N., R. 3 E.
18	"Copalis well"	Olympic Oil Co.	1901	847	Grays Harbor Co., Washington, 2½ miles N. of Copalis, SW. ¼, NW. ¼ Sec. 9, T. 19 N., R. 12 W.
	Eldorado	Eldorado Oil Co.	1902	350	Near Copalis
	Northwestern 1	Standard Oil Co. of California	1921	3805	Grays Harbor Co., 1 mile E. of Moclips, Sec. 8, T. 20 N., R. 12 W.
	Washington State 1	Standard Oil Co. of California	1921	4130	Grays Harbor Co., Sec. 16, T. 20 N., R. 12 W.
	Name unknown	Lease Holding Syndicate Co.	1927	4426	Northwest Oregon, Sec. 17, T. 3 N., R. 2 W.
	Benson Clatskanie 1	Texas Oil Co.	1945	2000 July 26	Columbia Co., Oregon, NE. ¼ Sec. 36, T. 7 N., R. 4 W.
20	Well 2	Coast Oil Co.	1936	Depth unknown	Coos Bay area, Oregon, Sec. 10, T. 28 S., R. 13 W.
	Dobbyns 1	Philips Petroleum Co.	1943	6941	Coos Co., Oregon, Cen. NW. ¼, SW. ¼ Sec. 28, T. 26 S., R. 13 W.
21	Brown 1	Lower Columbia Oil and Gas Co.	Before 1923	4808	Airport, Astoria, Oregon, NW. ¼, SW. ¼ Sec. 25, T. 8 N., R. 10 W.
22	Name unknown	Carters Producers and Refinery Syndicate (Willamette Petroleum Syndicate)	?	1880	Benton Co., Oregon, 2100 feet E. and 300 feet S. of NW. cor. Sec. 11, T. 12 S., R. 5 W.

drainage of the northern slope passes through numerous tributaries to Columbia River while that of the southern slope finds its way into several lakes lying within the Malheur Basin.

During the Middle Tertiary the larger part of eastern Oregon was covered with volcanic materials but later, after the uplift of the axial Blue Mountain range, this cover was removed locally and many of the underlying basement rocks were exposed. The uplift in the northeast corner of Oregon was so pronounced that the older rocks form most of the exposures, and the lavas occur in subordinate amounts as residual patches. Farther toward the southwest in east-central Oregon the older rocks are exposed in windows carved into the lavas and associated continental sediments. The lithologic character and geologic age of the pre-Tertiary rocks in the two areas of the Blue Mountains are so different that they can be best described separately.

Geologic investigations of the northeastern part of the Blue Mountains by Lindgren,[4] Goodspeed,[5] Gilluly,[6] Hodges,[7] Krauskopf,[8] Ross,[9] Smith,[10] and others

[4] Waldemar Lindgren, "Gold Belt of the Blue Mountains of Oregon," *U. S. Geol. Survey 22nd Ann. Rept.*, Pt. 2 (1900–01), pp. 561–776.

TABLE I

ROCKS OF BLUE MOUNTAINS, OREGON AND WASHINGTON

RECENT AND PLEISTOCENE	Alluvial deposits and small amounts of volcanic ash Morainic material and glacial outwash	
PLIOCENE MIOCENE OLIGOCENE AND EOCENE	Erosion Elevation and intensive erosion Lacustrine and fluviatile deposition Lacustrine and fluviatile deposition Erosion and planation	 Columbia River lavas 1–3,000 feet thick Older rhyolites and andesites
CRETACEOUS AND JURASSIC (?)	Folding, faulting, uplift, and erosion	
	Granodiorite and other associated rocks—metamorphism	
UPPER TRIASSIC	Hurwal formation	Metamorphosed shales, limestones and lenses of limestone. Upper Triassic fossils. 0–2,000 feet thick
	Martin Bridge formation	Metamorphosed limestone. 200–2,000 feet thick
	Lower sedimentary series	Shale, calcareous shale, argillaceous limestone, and hornfels. Partially metamorphosed. 1,500 feet thick. Upper Triassic fossils
PERMIAN	Clover Creek greenstone	Metamorphosed volcanic materials together with small quantities of conglomerate, limestone, and chert. 4,000 feet thick
PRE-PENNSYLVANIAN (?)	Elkhorn Ridge argillite	Metamorphosed tuffs, chert, limestone, and lavas. Argillites prevail. 5,000 feet thick
PRE-CARBONIFEROUS (?)	Burnt River schist	Schist, quartzite, and metamorphosed limestone 500 feet thick

present a fair idea of the areal distribution, lithology, structure, age, and possible origin of the different rock formations. These consist of metamorphosed sediments and volcanic materials of late Paleozoic and early Mesozoic age; granites, quartz diorites, *et cetera*, possibly Cretaceous in age; and several thousand feet of volcanic materials and sediments of continental origin which were formed during the Tertiary. These rocks may be classified as shown in Table I.

The pre-Tertiary metamorphic rocks exposed in the rugged higher parts of the

[5] G. E. Goodspeed, "Pre-Tertiary Metasomatic Processes in the Southeastern Portion of the Wallowa Mountains of Oregon," *Proc. Sixth Pacific Science Congress* (1939), pp. 399–422.

[6] James Gilluly, "Geology and Mineral Resources of the Baker Quadrangle, Oregon," *U. S. Geol. Survey Bull. 879* (1937), pp. 1–116.

[7] E. T. Hodge, "Geology of North Central Oregon," *Oregon State College Mon. 3* (1942), pp. 3–76.

[8] K. B. Krauskopf, "The Wallowa Batholith," *Amer. Jour. Sci.*, Vol. 241 (1943), pp. 607–28.

[9] C. P. Ross, "Geology of a Part of the Wallowa Mountains," *Oregon State Dept. Geol. and Min. Indus. Bull. 3* (1938), pp. 1–74.

[10] W. D. Smith and J. E. Allen, "Geology and Physiography of the Northern Wallowa Mountains of Oregon," *Oregon State Dept. Geol. and Min. Indus. Bull. 12* (1941), pp. 1–64.

Blue Mountains are for the most part older than those occurring in the windows toward the southwest and consist of schist, quartzite, crystalline limestone, and greenstone. Associated with them are extensive masses of granite. All of these rocks have been intricately deformed and eroded, and on the resulting surface rest great thicknesses of Tertiary volcanic materials. The metamorphic rocks originally consisted largely of shales, sandstones, and limestones of varying lithologic character and thickness which were deposited during the late Paleozoic and early Mesozoic upon the floor of differentially subsiding marine embayments of the Cordilleran trough. Intermittent volcanic activity permitted thick deposits of ash and flows of lava to accumulate on the sea floor and thus become intercalated with the marine sediments. Long periods of uplift and erosion may have intervened between epochs of subsidence as suggested by the unconformities between the different formations.

The Tertiary sediments and volcanics are separated from the older rocks by a profound angular and erosional unconformity. Igneous rocks of granitic and dioritic composition were formed possibly during the Cretaceous. During late Mesozoic and early Tertiary time, uplift accompanied by erosion caused the removal of large areas of metamorphosed sediments and the development of a pre-Miocene surface of considerable relief. Some of the valleys, which were carved into this surface, were filled early in the Miocene with deposits of ash and flows of andesite and rhyolite. Locally alluvial and fluviatile sands and gravels were deposited between the flows.

During the Miocene the surface of the Blue Mountains probably was only moderately higher than the area of the Columbia Plateau. The Columbia River lavas which were accumulating during the Miocene upon the differentially subsiding surface of the eastern Oregon and Washington area finally encroached upon and covered the Wallowa Mountains to a thickness of nearly 1,500 feet. Numerous diabase dikes which intersect the pre-Miocene rocks represent vents through which much of the lava came to the surface. The original differences in the altitude of the surface, the intermittent outpourings of lava and accumulation of ash deposits, and the varying amounts of subsidence of the area in time and place made possible the accumulation of considerable thicknesses of fluviatile and lacustrine deposits between the flows. For this reason, lithologically similar Miocene sedimentary deposits may not be entirely contemporaneous.

During the Pliocene and perhaps at the close of the Tertiary and early Pleistocene, the area of northeastern Oregon was arched upward possibly 5,000 feet and strongly faulted, thus permitting the removal by erosion of a large part of the Columbia River volcanics. Here and there small residual patches still remain even on the highest peaks.

Pleistocene glaciers sculptured and modified the previously eroded surface and the resultant Blue Mountains of to-day were produced.

The Paleozoic and early Mesozoic marine sediments of this area at an early time may have possessed source beds and retaining beds for oil and gas, but the

later processes of metamorphism would make impossible their existence at the present time. All the available geologic evidence leads to an interpretation that the northeastern part of the Blue Mountains is extremely unfavorable for the commercial occurrence of oil and gas.

Southwestern Extension of Blue Mountains

The broad axial upwarp which forms the southwest extension of the Blue Mountains into east-central Oregon is situated about 100 miles south of Columbia River at altitudes ranging from 4,000 to 5,000 feet. During the early Tertiary its surface was probably a little more elevated than the areas immediately north and south, and the volcanic materials which were accumulating there did not succeed in covering this region until near the close of the Miocene. A later post-Miocene upwarp permitted tributaries of the John Day River to erode through the relatively thin lava covering and expose a thick section of marine Jurassic sedimentary rocks. Marine Cretaceous sediments and continental deposits of Eocene and Oligocene age are also exposed locally. Investigation made by Lupher[11] shows that the sequence of Jurassic formations ranges in thickness from 14,640 to 16,262 feet. These beds consist largely of black shale with subordinate amounts of limestone, argillaceous limestone, and sandstone. They are mostly conformable on one another although in certain places unconformities do exist. They were strongly folded in pre-Tertiary time with axes trending in a general east-to-northeast direction, thus suggesting that these sediments may lie in a buried trough whose northern border does not extend as far north as Columbia River. It is possible that these Jurassic beds may extend westward into the floor of the ocean and lie deeply buried beneath the Tertiary lavas of the Cascade Mountains and the thick sequence of Tertiary sediments of the Coast Ranges. Table II shows a classification of the Jurassic strata by Lupher.

Tertiary continental sediments are exposed in north-central Oregon through windows beneath the Columbia River lavas and consist of the Eocene Clarno formation and the John Day formation of upper Oligocene and lower Miocene age. In the same general region occur the Mascall formation of Miocene age and the Rattlesnake formation of middle Pliocene age, both continental in origin. On the basis of floral evidence the Deschutes formation in the valley of Deschutes River is regarded as lower or middle Pliocene by Chaney[12] and the Latah formation in the northern part of the Columbia Plateau in Washington as Miocene. The Ellensburg formation exposed north of Columbia River in Washington consists of fluviatile and lacustrine deposits and is thought to range from late Miocene to Pliocene. All these sediments accumulated under somewhat simi-

[11] R. L. Lupher, "Jurassic Stratigraphy of Central Oregon," *Bull. Geol. Soc. America*, Vol. 52 (1941), pp. 219–70.

[12] Ralph W. Chaney, "The Deschutes Flora of Eastern Oregon," *Carnegie Inst. Washington Pub. 476*, Pt. 4 (1938), pp. 185–216.

——, "The San Pablo Flora of West Central California," *ibid.*, Pt. 5 (1938), pp. 244–45.

lar conditions but the deposits of a given formation in different places are not everywhere contemporaneous.

The Clarno[13] formation, about 400 feet thick, is exposed in the John Day Basin where it rests unconformably on the upturned and beveled edges of Cretaceous sedimentary rocks and is overlain by the John Day beds. It is composed mainly of volcanic materials consisting of partially decomposed plant-bearing tuffaceous shales which grade into a course tuff together with agglomerates and intercalated flows of andesite. These beds which range in color from various shades of gray, green, blue, and gray are probably lacustrine in origin and the contained fossil plants suggest a late Eocene age.

The John Day[14] beds which are widely spread through the John Day Basin rest unconformably on the Clarno formation and range from 1,500 to 2,000 feet

TABLE II

JURASSIC ROCKS OF CENTRAL OREGON

Age	*Group*	*Formation*	*Thickness (Feet)*
UPPER JURASSIC ?		Lonesome	4,000
		Unconformity ?	
EARLY UPPER JURASSIC		Trowbridge shale	
		Unconformity	
EARLY MIDDLE JURASSIC	Izee	Snowshoe	2,800
		Hyde	1,080–1,512
		Unconformity ?	
	Colpitts	Warm Springs	100–300
		Weberg	100–272
		Unconformity	
LATE LOWER TO EARLY UPPER LIAS	Mowich	Nicely shale	134–228
		Suplee	35–150
		Robertson	150–500
		Donovan	2,241–2,500

thick. They consist largely of pyroclastic materials and redeposited decomposed tuff with rhyolite and andesite flows near the middle. The formation has been subdivided into lower, middle, and upper units. The lower consists of buff shales of trachytic composition and the middle and upper of blue and red beds of andesitic character. Sands and gravels are also present. These beds, which are overlain unconformably by the Columbia River volcanics, may have accumulated in

[13] J. C. Merriam, "A Contribution to the Geology of the John Day Basin," *Univ. California Dept. Geol. Bull.*, Vol. 2 (1901), pp. 269–314.
F. C. Calkins, "A Contribution to the Petrography of the John Day Region," *ibid.*, Vol. 3 (1902), pp. 109–72.

[14] J. C. Merriam, *op. cit.*
F. G. Calkins, *op. cit.*

numerous small lakes situated on the surface of a slightly warped plain. The fossil plants are thought to indicate an age ranging from upper Oligocene to lower Miocene.

The Mascall[15] formation exposed in the valley of the East Fork of John Day River accumulated in slight depressions upon the surface of the Columbia River volcanics. It consists of 800 to 1,000 feet of light-colored to brownish and reddish beds of ash and tuff together with small amounts of sand and conglomerate all of which are probably lacustrine in origin.

The Rattlesnake[16] formation ranging from 30 to 100 feet thick rests unconformably on the upturned and eroded edges of the Mascall formation and consists of coarse basal gravels overlain by soft brown tuffs capped with 30 feet of rhyolite. It is believed to be middle Pliocene in age on evidence afforded by fossil vertebrates.

The folded Jurassic beds exposed in the windows through the lavas are greatly indurated but not metamorphosed. The writer is not aware of any reported oil seeps in these rocks. There is no evidence to suggest their wide distribution beneath the Miocene basalts, and it is probable that they are limited to a comparatively narrow folded trough more or less confined to the area of the axial upwarp of the Blue Mountains.

Columbia Plateau

The Columbia Plateau comprises that part of eastern Washington south of the Okanogan Highlands and east of the Cascade Mountains and extends into eastern Oregon about 150 miles as far south as the axial uplift of the Blue Mountains. It spreads eastward into Idaho as far as the foothills of the Rocky Mountains. The drainage of the plateau is through several large streams into Columbia River and ultimately to the ocean. The average altitude of the central part is under 2,000 feet but increases to 3,000 feet near the Idaho line, 4,000 feet along the axial upwarp in north-central Oregon, 2,500 feet along the eastern slope of the Cascade Mountains, and 2,200 feet along Columbia River near the south border of the Okanogan Highlands. The northern and western margins are deeply dissected by Columbia River and the southeastern part by Snake River. The floor of Columbia River is less than 500 feet above sea-level at its junction with the Snake River and gradually descends nearly to sea-level in the gorge through the Cascade Mountains.

The surface of the plateau includes approximately an area of about 52,000 square miles. Nearly 48,000 square miles of this area consists of numerous nearly horizontal basaltic lava flows, pyroclastic materials, tuffs, and here and there sediments of continental origin. These extrusive materials accumulated on

[15] J. C. Merriam, *op. cit.*
F. G. Calkins, *op. cit.*

[16] *Ibid.*

a floor of considerable relief as evidenced by such topographic features as Steptoe Butte in Washington which rises 1,000 feet above the lava surface. This mountain is composed of granite and quartzite which formed a part of the pre-volcanic topography and was surrounded by lava flows but never covered.

The name Columbia River lavas was applied to these volcanic materials by Russell,[17] and for the most part they are of probable middle Miocene age although locally older and younger lavas and tuffs are associated with them. These lavas gradually rise toward the southwest and pass out of the Columbia Plateau and into the broad north-and-south axial warp of the southern part of the Cascade Mountains in Washington. Some of the flows continue still farther west to the Pacific Ocean where they are encountered intercalated with the marine sediments of the middle Miocene Astoria formation.

Subordinate amounts of locally deposited fluviatile and lacustrine sediments which occur intercalated within the lava flows probably accumulated in temporary shallow depressions caused by the damming of stream valleys during the intermissions in laval extrusions. These continental sedimentary deposits are restricted in their distribution in eastern Washington but become more prominent in the north part of eastern Oregon near the southwest axial extension of the Blue Mountains where they have been exposed by erosion.

In general, the Columbia River lavas lie in a low shallow downwarp which may have been in the process of forming as accumulation progressed. The maximum thickness is probably near the axis of the downwarp. Toward the margins of the basin the number of flows and the total thickness become progressively less although this apparent decrease may in part be due to more effective removal by erosion. The volcanics in the western margin of the basin in Washington have been folded into several northwest- and southeast-trending anticlines and synclines with low-dipping flanks. In some cases steep-angle faults lie close to the axes. These folds plunge southeasterly and rise and flare out on the eastern slopes of the Cascade Mountains. The thickness of the Columbia River lavas and the lithologic character of the rocks on which they rest are of importance in considering the possibilities for oil or gas in this region. Evidence is available in two areas which throws some light on the thickness. In southeast Washington Snake River has carved its canyon down through the basalt to a depth of more than 5,000 feet. The lava is at least 4,000 feet thick in the walls of the canyon and rests on granite in the bottom of the gorge. In 1938 a well was drilled for the purpose of obtaining oil and gas upon an anticlinal axis in the Frenchman Hills in Washington near the northern end of the Columbia Plateau. This drill hole started at the surface in lava and continued in lava to the bottom of the well at a depth of more than 4,000 feet without reaching the base of the flows. There is no evidence concerning

[17] I. C. Russell, "A Geological Reconnaissance in Central Washington," *U. S. Geol. Survey Bull. 108* (1893), pp. 1–104.
———, "Notes on the Geology of Southwestern Idaho and Southeastern Oregon," *ibid., Bull. 217* (1903), pp. 1–83.

the thickness of the lava beneath the bottom of the hole. Farther south in the Rattlesnake Hills several wells have been drilled for gas to depths of more than 4,000 feet without encountering the base of the volcanics.

Beneath the Columbia Plateau the character of the rocks on which the lavas rest may be interpreted from their exposures around the margins of the basin. Such rocks are well exposed in eastern Washington near the Idaho line and along the east-to-west course of Columbia River at the southern margin of the Okanogan Highlands. These rocks are entirely composed of schist, crystalline limestone, and quartzite along with granite and similar igneous rocks. The volcanics in the western margin of the basin along the eastern slope of the Cascade Mountains rest on similar metamorphic rock from the lower end of the Okanogan Valley to the lower end of Lake Chelan but farther south lap onto a floor composed of folded older lavas and continental sediments of the Swauk and Roslyn formations of Eocene age together with older metamorphic and igneous rocks. The prevailing trend of the areas occupied by Eocene continental sediments suggests that as they leave the Cascade Mountains they extend only a short distance east beneath the Columbia Plateau. The evidence obtained from the margin of the lavas of the Columbia basin leads to the interpretation that the greater part of the floor on which these volcanics rest in Washington and the extreme northern part of Oregon is composed of granites and metamorphic rocks. Such information indicates that any attempt to drill for oil in this area would require penetrating at least 4,000 feet of lava with the probability of entering a basement of granite or metamorphic rock. It is possible that the folded and beveled basement rocks of marine Jurassic age exposed in windows through the lavas on the north slope of the southwest extension of the Blue Mountains in eastern Oregon may extend a short distance north but not as far as Columbia River.

Cascade Range

The Cascade Range rises rather abruptly several thousand feet from a plateau immediately north of the Canadian boundary and extends southward through Washington and Oregon into northern California—a distance of nearly 600 miles with a width ranging from 60 to more than 100 miles. The northern part of the range as far south as Snoqualmie Pass differs from the part farther south both topographically and geologically. It is composed largely of pre-Tertiary plutonic and metamorphic rocks,[18] whose eroded and beveled surface was uplifted and strongly dissected with resultant crests whose altitudes range from

[18] G. O. Smith and F. C. Calkins, "A Geological Reconnaissance across the Cascade Range near the Forty-Ninth Parallel," *U. S. Geol. Survey Bull. 235* (1904), pp. 1–103.

Bailey Willis, "Physiography and Deformation of the Wenatchee-Chelan District, Cascade Range," *ibid., Prof. Paper 19* (1903), pp. 41–97.

G. O. Smith, "Description of the Mount Stuart Quadrangle," *ibid., Geol. Atlas Folio 106* (1904).

G. O. Smith and F. C. Calkins, "Description of the Snoqualmie Quadrangle," *ibid., Folio 139* (1906).

6,000 to 8,500 feet. Here and there masses of granitic and metamorphic rock rise above the general level of this surface, and at an earlier time may have been monadnocks. South of Snoqualmie Pass these older rocks pass beneath a very thick cover of Tertiary volcanic materials and subordinate amounts of intercalated continental sediments all of which are gently warped upward along a north-and-south axis.

During the Pleistocene several volcanic cones were built up over local eruptive centers, giving rise to Mt. Baker, Mt. Rainier, Mt. Adams, Mt. St. Helens, Mt. Hood, and smaller peaks farther south in Oregon. The surface features of the range have been additionally modified by Pleistocene glacial sculpture and at many places small alpine glaciers still exist at altitudes of more than 5,000 feet.

The northern part of the range is separated from the Okanogan Highlands by the north-south course of Okanogan Valley, and from Lake Chelan southward the eastern slope gradually passes downward and merges into the surface of the Columbia Plateau. The western slope descends to sea-level along the Puget-Sound-Willamette trough; part of its course east of Seattle is broken by a steep escarpment as the result of faulting.

The rocks of the northern Cascade Range with the exception of the plutonics may be classified as shown in Table III.

The broad geological features of the northern Cascade Mountains of Washington are fairly well known from the published reports and maps of the United States Geological Survey, the Washington State Geological Survey, and the scientific journals. The older formations of early Paleozoic and possibly pre-Cambrian age are very strongly metamorphosed and deformed and consist largely of gneiss, quartzite, crystalline limestone, amphibolite schist, and greenstone together with granites and other associated plutonic rocks. Other greatly indurated but not strongly metamorphosed rocks include the Peshastin formation, the Anarchist series, the Cultus formation, the Shukson formation, and the Pasayten formation. These formations are folded or faulted into the older rocks and along with them have suffered extensive erosion. The Peshasten formation which is exposed in the valleys of the Peshastin and Skykomish rivers is more than 3,000 feet thick and consists of quartzites, slates, and limestones which have furnished brachiopods and trilobites of Ordovician age. Its exact areal distribution is not entirely known.

Phyllites, meta-conglomerates, quartzites, limestones, greywackes, chloritic schists, greenstones, and meta-andesites are widely distributed in the eastern part of the Cascade Mountains on both the east and west sides of Okanogan Valley. These rocks have been named the Anarchist[19] series and the limestones have yielded marine fossils of Pennsylvanian and Permian age. Some of the metamorphic rocks in the western slope of the Cascades probably belong to this group.

[19] R. A. Daly, "North American Cordillera at the Forty-Ninth Parallel," *Canada Geol. Survey Dept. Mines Mem. 38* (1912), pp. 389–92.

The Cultus[20] formation occurs in the western slope of the Cascade Mountains along Cultus Ridge just south of the Canadian boundary. It consists of dark gray argillites with subordinate amounts of interbedded gray sandstone and fine conglomerate but with no limestone or volcanic products. These beds range from 1,000 to 3,000 feet thick and have yielded a few marine invertebrate fossils of probable Triassic age. They have been folded and dips ranging from 30° to 80° are common.

Strongly indurated and folded sandstones and shales containing Upper Jurassic mollusks are exposed in the Cascade Mountains north and northwest of Mt. Baker in the valley of Nooksak River. Very little information is available concerning the thickness and structure of these sediments. Other indurated sandstones and shales are reported as occurring in the older rocks east and west of Okanogan Valley.

TABLE III

ROCKS OF NORTHERN CASCADE RANGE, WASHINGTON
(Plutonics omitted)

Age	*Formation*	
	Ellensburg	Lacustrine and fluviatile deposits
MIOCENE (MIDDLE ?)	Yakima basalt	
LOWER MIOCENE	Upper Keechelus	Andesitic flows, agglomerates, and tuffs
UPPER OLIGOCENE	Lower Keechelus	Breccias and metasomatic-replacement alteration products
EOCENE	Roslyn and Guye	Lacustrine and fluviatile deposits
	Teannaway basalt	Basalt flows and intrusive dikes
	Swauk	Lacustrine and fluviatile deposits
CRETACEOUS	Pasayten	Marine sediments which may in part be continental
UPPER JURASSIC	Shukson	Marine sediments; partly metamorphosed
TRIASSIC	Cultus	Marine shale and limestone partly metamorphosed
PERMIAN AND PENNSYLVANIAN	Anarchist series	Metamorphosed sediments and lavas
ORDOVICIAN	Peshastin	Quartzites, slates, and limestones
EARLY PALEOZOIC OR PRE-CAMBRIAN	Gneiss, marble, ambolite schist, and quartzite	Invaded by plutonic rocks

The name Pasayten formation has been applied to about 6,000 feet of sedimentary rock exposed in Pasayten Valley at the summit of the Cascade Range on

[20] R. A. Daly, *op. cit.*, pp. 516–17.

both sides of the Canadian boundary. The formation is composed of a lower black shale member 1,000 feet thick followed by 500 feet of sandy conglomerate. The upper part of the formation consists of 4,500 feet of dark, well bedded shale which ordinarily is well cemented and strongly folded and in places is cut by igneous dikes. These beds north of the international boundary and between the Pasayten and Skagit rivers are reported by Daly[21] to be 30,000 feet thick. Fossil mollusks obtained from these beds indicate a Lower Cretaceous age for a part of the formation.

The Paleozoic and Mesozoic formations already described together with granites and other plutonic rocks were subjected to extensive erosion and by early Tertiary time a large part of the northern Cascades was eroded to a region of low relief. Upon this surface during the Tertiary there accumulated locally great thicknesses of lavas and continental sediments, including the Swauk formation, the Teannaway basalt, the Roslyn formation, the Guye formation, the Keechelus andesitic series, and the Ellensburg formation.

The Swauk formation has been faulted down into the older rocks of the Cascades in an elongate area along the southwest side of Lake Chelan. It extends from the summit of the range southeastward to Columbia River and then passes beneath the westward margin of the Columbia River basalt but probably does not extend a great distance east. It also forms extensive outcrops in the Wenatchee Mountains and in other isolated areas in the northern Cascades, where it rests unconformably on the older formations and also beneath the Teannaway basalt. The formation ranges from 4,000 to 8,000 feet thick and consists mainly of medium- to coarse-grained thickly bedded light gray arkosic sandstone with thick layers of conglomerate near the base at certain localities. Carbonaceous sandy shales are moderately abundant in the lower part and occur here and there in the upper. The fossil plants suggest an early Eocene age, and it is possible that the formation may have begun to accumulate during late Cretaceous. These deposits are probably both lacustrine and fluviatile in origin and accumulated on the flood plains of broad valleys occupied by major streams which flowed west to the ocean. At the close of Swauk time these deposits were folded into northwest-trending anticlines and after erosion there was produced an uneven surface upon which 1,000 to 5,000 feet of basaltic lava poured out. This volcanic material which came to the surface through many nearly parallel fissures now represented by diabase dikes has been named the Teannaway basalt. Later, and perhaps during the early Eocene, these volcanic materials were strongly folded and eroded with the development of a new surface which northwest of Yakima was downwarped so as to form a new Eocene basin. Late in the Eocene there accumulated 2,000 to 3,500 feet of light gray medium to coarse sandstone and subordinate amounts of carbonaceous shales together with several commercial coal seams. These beds of both lacustrine and fluviatile origin have been named the Roslyn formation. The basin of deposition was smaller than that in which the Swauk

[21] R. A. Daly, *op. cit.*, pp. 479–89.

formation accumulated. The Roslyn beds were folded, eroded, and covered unconformably by the Keechelus volcanics and the Columbia River lavas.

At the summit of the Cascade Mountains near Snoqualmie Pass occur 3,500 feet of sandstone, shale, and conglomerate which have been named the Guye[22] formation. It is entirely of continental origin and of limited areal extent. It is reported by Warren to lie unconformably beneath the Keechelus volcanics and may be late Eocene in age and possibly in part contemporaneous with the Roslyn formation.

The Keechelus andesitic series is exposed in the western part of the Cascade Range south of Snoqualmie Pass and possibly continues southward to Columbia River although its areal distribution is not entirely known at present. It is reported by Warren[23] to pass beneath the Columbia River basalts on the east side of the Cascades. The series consists of a sequence of breccias, lavas, tuffs, and intercalated sediments of lacustrine and fluviatile origin, together with flows of basalt and rhyolite, which average 2,000 feet thick, although locally in White River Canyon this series increases to 5,000 feet. In the Mt. Aix Quadrangle east of Mt. Rainier, Warren[24] has subdivided the series on the basis of an unconformity into an upper and lower division and has named the upper the Fifes Peak andesite. The rocks of the lower part are largely breccias which in certain places have formed as the result of metasomatic alteration of sedimentary rocks. The upper part is composed largely of lava flows, pyroclastic materials, and continental sediments. In the Mt. Aix area the lower jaw of an oredont was obtained from a thick section of sedimentary rock intercalated in the lower Keechelus which suggests an age for those beds ranging from middle Oligocene to lower Miocene.

The Columbia River lavas, or volcanics in part of equal age, extend westward into the southern Cascades of Washington and continue southward through the Cascades of Oregon to the California line. These lavas, together with volcanic material of later Tertiary and Pleistocene age, have been raised into a broad north-and-south axial upwarp, and at no locality have the underlying rocks been exposed as the result of erosion. Some of the marine Tertiary rocks of the Willamette Valley in Oregon pass beneath the western margin of the Cascades and may underlie the volcanics for a short distance toward the east. It is probable that the marine Jurassic sediments exposed in the windows along the southwest extension of the Blue Mountains in eastern Oregon may occupy a narrow east-and-west belt beneath the lavas in the middle part of the Cascades of Oregon and continue to the ocean deep beneath the Tertiary sediments of the Coast Range.

[22] G. O. Smith and F. C. Calkins, "Description of the Snoqualmie Quadrangle," *U. S. Geol. Survey Geol. Atlas Folio 139* (1906).

[23] W. C. Warren, "Relation of the Yakima Basalt to the Keechelus Andesific Series," *Jour. Geol.*, Vol. 59 (1941), pp. 795–814.

[24] *Ibid.*

The Ellensburg formation occurs in Washington in the eastern slope of the Cascade Mountains and on the Columbia River lavas in the western margin of the Columbia Plateau. The formation is in part fluviatile and in part lacustrine and consists of 800 to 1,600 feet of sandstones, shales, tuffs, lava flows, and conglomerates largely derived from volcanic materials. The sections exposed at different localities are not everywhere contemporaneous and may in part have accumulated in small separate basins each with a slightly different history. Evidence afforded by fossil leaves suggests a late Miocene age, but it is probable that some of the deposits accumulated during the Pliocene. In some localities deposition of the formation may have begun late in the middle Miocene while the Columbia River lavas were being extruded.

No marine Tertiary sediments are known to occur in the Cascade Mountains or in eastern Washington and Oregon. For reasons already presented the granites and highly metamorphosed rocks of the northern Cascade Mountains of Washington may be considered as very unfavorable for the occurrence of commercial deposits of oil and gas. The greatly indurated sediments of the Cultus and Pasayten formations might possibly be considered as worthy of some geologic examination although no indications of oil or gas are reported from them. The continental sediments of Tertiary age are largely of fluviatile origin and accumulated under unfavorable conditions for the development of source beds for oil and gas. It is possible that small quantities of methane gas may have been formed in the lacustrine clays from vegetable material, but these sediments are of limited areal extent and probably of doubtful commercial importance.

Klamath Mountains

The Klamath Mountains situated in southwestern Oregon and northwestern California form a distinct topographic unit within the Coast Range. The Oregon part of the Klamath Mountains is composed of the Rogue River Mountains in the north and the Siskiyou Mountains in the south; the latter extend into California. They form a deeply dissected warped plain which rises from the surface of the Coast Range south of Coos Bay to an average altitude of more than 5,000 feet. Ridges representing an older topography rise above this plain to altitudes of 7,600 feet in Oregon and more than 9,000 feet in California. The Klamath Mountains are separated from the southern end of the Cascade Mountains and the northern end of the Sierra Nevada by a mountainous knot of lower relief composed of the western extension of the Tertiary volcanics of Oregon and northeastern California. A complicated physiographic history of the Klamath Mountains[25] has been interpreted from a study of the altitudes of numerous dissected terraces. Late in the Cretaceous or early Eocene a plain was carved out of the Paleozoic and Mesozoic rocks with ridges or monadnocks rising from 1,000 to 4,000 feet above its surface. Later this plain was raised differentially from 5,000

[25] J. S. Diller, "Topographic Development of the Klamath Mountains," *U. S. Geol. Survey Bull. 196* (1902).

to 6,000 feet above sea-level. This surface was further complicated by faulting, and the major streams such as the Coquille, Rogue, and Klamath rivers which had been flowing west to the ocean before uplift became entrenched with the development of canyon-like valleys more than 2,000 feet deep.

The oldest rocks on the Oregon side of the Klamath Mountains consist of mica schist and slates with well developed cleavage which may be equivalent to the Abrams formation in northern California. The age of these rocks is unknown although they are believed to be older than Devonian and possibly pre-Cambrian. Banded slates, limestones, sandstones, and conglomerates which are greatly indurated, compressed, and faulted rest unconformably on the older rocks. These less metamorphosed sediments are thought to be Devonian and Carboniferous in age. Associated with these formations are widespread masses of intrusive and extrusive rocks.

A series of semi-metamorphosed sedimentary and igneous rocks named the Dothan and Galice formations occur in the northern slope of the Klamath Mountains of Oregon. As originally defined by the United States Geological Survey,[26] the Dothan was thought to be the equivalent of the Franciscan formation of California and younger than the Galice formation which had been correlated with the Mariposa formation of the Sierra Nevada. However, as the result of recent investigations by Taliaferro,[27] it is stated that the Dothan is the older of the two and that it grades upward into the Galice formation. The Dothan is composed of black slates, sheared arkosic sandstones, conglomerates, and impure limestone ranging from 1,000 to 6,000 feet thick. Near the top 600 feet of schistose rhyolite, andesite, tuff, and agglomerate are interbedded with black slate which contains marine Galice fossils. Above these are 2,000 feet of black slates, sandstones, and conglomerates with intercalated greenstones. These beds have been strongly folded and commonly stand at high angles. The fossils obtained from the Galice formation correspond with those from the Mariposa formation in California and are thought to indicate an (Upper Jurassic) Oxfordian age. The Galice and Dothan formations are separated from the (Devonian) May Creek formation by a thrust fault, and are overlain unconformably by the Franciscan.

The Franciscan formation which is widely distributed in the Coast Range of California occurs in the northern slope of the Klamath Mountains in southwestern Oregon where it constitutes the lower part of a series of sediments which have been mapped as the Myrtle formation.[28] This lower part later was named the Dillard formation.[29] Lithologically it is similar to the Franciscan of California,

[26] J. S. Diller, *op. cit.*
——, "The Mesozoic Sediments of Southwestern Oregon," *Amer. Jour. Sci.*, 4th Ser., Vol. 23 (1907), pp. 401–21.

[27] N. L. Taliaferro, "Franciscan-Knoxville Problem," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27 (1943), pp. 109–219.

[28] J. S. Diller, "Description of the Roseburg Quadrangle," *U. S. Geol. Survey Geol. Atlas Folio 49* (1898).

[29] G. D. Louderback, "The Mesozoic of Southwestern Oregon," *Jour. Geol.*, Vol. 13 (1905), pp. 514–55.

consisting of arkosic sandstone, conglomerate, radiolarian chert, dark sandy shale, and intercalated vesicular and pillow lavas. These sediments and igneous flows are intruded by diabase, gabbro, and peridotite which in most places is altered to serpentine. Glaucophane and other schists are commonly present as pneumatolytic contact rocks. The formation is between 8,000 and 10,000 feet thick in southwest Oregon.

The upper part of the Myrtle formation is now considered as uppermost Jurassic and Cretaceous and equivalent to the Knoxville, Paskenta, Horsetown, and Chico formations of California. The Knoxville and Paskenta beds range from 500 to 1,000 feet thick and consist of dark gray sandstones with smaller amounts of shale and conglomerate near the base. The Horsetown and Chico beds are mainly sandstone with a combined thickness of about 600 feet. The Cretaceous formations are strongly folded and extend from the Klamath Mountains northward where they pass unconformably beneath the Tertiary formations of the Coast Range.

Coast Range

The name Coast Range has been applied to the mountainous area along the western border of the continent from Vancouver Island southward to Lower California. It has been divided into the following topographic units: Vancouver Island, Olympic Mountains, Coast Range of southwest Washington and western Oregon, Klamath Mountains, and the Coast Range of California. It is separated from the Cascade Mountains by the nearly parallel north-and-south Puget Sound-Willamette Valley trough.

Vancouver Island and the Olympic Mountains on the north, like the Klamath Mountains on the south, have been uplifted high above sea-level and deeply eroded in contrast to the intervening part of the range in southwest Washington and western Oregon. As a result pre-Tertiary formations are exposed at the north and south ends, but are completely buried beneath Tertiary deposits in the intervening area. The present-day topographic features of both Vancouver Island and the Olympic Mountains are the result of two major intervals of diastrophism which affected the Pacific Coast region. The earliest, which occurred during late middle and possibly early late Miocene, produced two nearly parallel northwest-southeast-trending upwarps which extended from the ocean eastward across the present site of the Cascade Mountains. The roots of the north range may be observed in Vancouver Island, the San Juan Islands, and in the northern Cascade Mountains of Washington. The southern range extended from the Olympics across the present site of Puget Sound into and through the Cascade Mountains. In between was a structural geosynclinal downwarp. At the close of the Pliocene and probably during the earliest Pleistocene a second interval of intense diastrophism was involved which superimposed upon these earlier structures the nearly parallel north-and-south Coast Range and Cascade Mountains with the intervening downwarp. As a result Vancouver Island and the Olympic Mountains became separate topographic units.

Vancouver Island is separated from the Canadian mainland by a long winding marine channel and from the Olympic Mountains by the Strait of Juan de Fuca. The island with mountains which attain altitudes of 9,000 feet is partially crossed by marine channels resulting from Pleistocene subsidence. The surface features in general have been profoundly modified by glacial scouring. The greater part of Vancouver Island is composed of a complex of pre-Tertiary metamorphosed sediments and igneous rocks.[30] On these rest more than 10,000 feet of moderately indurated marine sandstones and shales of Cretaceous age. These occur mainly on the northeast margin of the island where they have been folded and faulted down into the older rocks. The southeast margin of the island is overlapped with a thick series of Eocene submarine volcanic materials overlain by Oligocene marine sediments of the same character as those farther south in the Coast Range in Washington and Oregon. The possibility for the commercial occurrence of oil and gas in the older metamorphic and igneous rocks is probably negligible, but the thick section of Cretaceous coal-bearing sediments is perhaps worthy of future geological examination. The marine Tertiary beds on the southeast flank of the island are very limited and for the most part shore deposits. The San Juan Islands in Washington are the southeastern extension of Vancouver Island and lie within the bowed-down Puget Sound trough. They represent a drowned topography and consist of old metamorphic and igneous rocks of the same lithologic character and age as those in Vancouver Island. Erosional residuals of Cretaceous sediments are exposed along their northern border.

The Olympic Mountains occupy an area of about 4,000 square miles with an average altitude of more than 5,000 feet. The higher crests in the center of the mass rise to altitudes of 8,300 feet. The main drainage divide extends from the coast south of Cape Flattery in general S. 65° E. and coincides approximately with the northwest and southeast axial upwarp of late middle Miocene time already mentioned. The northeast and southwest slopes are traversed by deep valleys with steep sides and intervening sharp crests which form an extremely rugged topography. The eastern end, as the result of the late Pliocene diastrophism, plunges down abruptly and forms the western border of the Puget Sound trough.

The site of the Olympic Mountains[31] was probably near or below sea-level during much of the Tertiary until near the close of the middle Miocene. The axial uplift which followed immediately arched the Tertiary igneous and sedimentary sequence high above sea-level, and subsequent erosion removed this covering from the axial part. This pattern was modified by the late Pliocene transverse north-and-south folding with the resultant topographic form of the present mountains. The uplifted and eroded Tertiary lavas and overlying marine sediments form a horseshoe-like rim around the north, east, and south sides of the

[30] C. H. Clapp, "Preliminary Report on Southern Vancouver Island," *Canada Dept. Mines, Geol. Survey Branch Mem. 13* (1912), pp. 1–208.

[31] C. E. Weaver, "Tertiary Stratigraphy of Western Washington and Northwestern Oregon," *Univ. Washington Pub. Geol.*, Vol. 4 (1937), pp. 17–36, 119–46, 173–75, 191–97, 198, 207.

mountains with the open end toward the northwest. The rocks of the interior are known only in a general way. They consist of more than 10,000 feet of nonfossiliferous arkosic sandstone named the Solduc formation which were strongly folded in pre-Tertiary or very early Eocene time. Other somewhat similar sandstones and shales are present but have not been described. These formations are not metamorphosed but are differentially indurated. No granites or other associated plutonic rocks are known at the surface but there is a possibility that such deep-seated rocks may exist at no great depth beneath the surface and thus account for the great regional variation in the amount of induration. The eroded surface carved out of these rocks formed a plain which may have extended eastward and southward throughout a large part of Oregon and Washington during the early part of the Eocene. Upon this differentially subsiding coastal plain there accumulated during the Tertiary an average of more than 15,000 feet of submarine lavas and marine sediments.

The central part of the Olympic Mountains has been subjected to complex faulting and a part of the overlying Tertiary sediments which were not removed by erosion are faulted down into the older rocks but the structural details are not at present known. The middle Miocene sandstones of the Astoria formation resemble lithologically the sandstones of the Solduc formation of pre-Tertiary age and at one time were mapped with them as a single stratigraphic unit—the Hoh formation.[32] The Astoria sandstones occur in the sea cliffs on the west side of the Olympic Peninsula and contain indications of oil in the form of very small seepages and of sediments which yield an odor of oil when freshly broken. These rocks have been folded and eroded and the structures extend westward into the floor of the ocean. The coast line has receded and it is possible that the sandstones west of the coast may gradually pass into shales. The Astoria rocks should be differentiated from the older Solduc sandstones in future mapping, and the western border of the Olympic Mountains is worthy of detailed geologic examination for the purpose of interpreting the conditions for the occurrence of oil and gas.

Table IV presents a classification of the rock formations as known in the Olympic Mountains.

Coast Range between Olympic and Klamath Mountains

The entire area[33] of the Coast Range between the Olympic Mountains on the north and the Klamath Mountains on the south together with most of the Puget Sound-Willamette trough is composed exclusively of Tertiary volcanic and sedimentary rocks. These materials have a total maximum thickness of 30,000 feet although a complete stratigraphic section of all the formations is not present in any one locality. These rocks accumulated in continuously changing embayments

[32] C. E. Weaver, "The Tertiary Formations of Western Washington," *Washington Geol. Survey Bull. 13* (1916), pp. 67–77.

[33] C. E. Weaver, "Tertiary Stratigraphy of Western Washington and Northwestern Oregon," *Univ. Washington Pub. Geol.*, Vol. 4 (1937), pp. 1–266.

TABLE IV

ROCKS OF OLYMPIC MOUNTAINS, WASHINGTON

Age	*Formation*	
PLEISTOCENE	Glacial deposits	Diastrophism. Development of north-south structures. Forming of present Puget trough and present Olympic Mountains
PLIOCENE	Quinault, Quillayute, and Montesano	Pacific coast farther west than to-day. Minor downwarping of plain on southwest side of Olympic Mts. below sea-level and local eastward transgression of sea, forming embayments within which 5,000 feet of marine sediments were deposited
UPPER MIOCENE	*Diastrophism, erosion, uplift, and local planation*	Compressional forces produced northwest-southeast upwarps and intervening downwarps. First Olympic range formed which extended from ocean southeastward into east side of present site of Cascade Mts. Present site of Puget Sound Basin occupied by continuation of Olympics. Diastrophism followed by erosion and development of northward-trending erosional valleys which were depressed below sea-level at close of Pliocene, modified by glacial action, and form present arms of Puget Sound
MIDDLE MIOCENE	Astoria	Marine embayments on north and south sides of Olympic Mts. Deposition of 4,000 feet of sandstone and subordinate amounts of shale with some thin layers of basalt
LOWER MIOCENE	Upper Twin River	Marine thick-bedded sandy shales on south shore of Strait of San Juan de Fuca and in Puget Sound Basin
UPPER OLIGOCENE	Blakeley = Lower Twin River	Type section in Bremerton Inlet. 8,000 feet interstratified thin layers of shale and sandstone, massive sandstones, sandy shales, and thick beds of conglomerate with general east-west strike and steep north dip and all in north limb of former east extension of Olympic Mts. Occurs also on north flank of Olympic Mts.
MIDDLE OLIGOCENE	Lincoln (including "Unnamed shale" and Quimper sandstone)	Type section upper Chehalis Valley in southwest Washington. Section 4,000 feet thick on north and south flanks of Olympic Mts. Composed of thick-bedded medium-grained marine very shaly sandstones and conglomerates near base. Deposited in embayments which extended eastward to present site of Cascade Mts. Area of Olympic Mts. probably a low plain near sea-level and locally covered with marine water
LOWER OLIGOCENE AND UPPERMOST EOCENE	Lyre conglomerate	Lyre conglomerate overlain by Townsend shale on north flank of Olympic Mts. and in general thinning from east to west. Equivalent of Keasey formation in southwest Washington and northwest Oregon. Deposited in local marine basins of small extent
UPPER EOCENE		Cowlitz formation, if present, represented only by thin layers of sandstone in northeast corner of Olympic Peninsula. Farther east represented by great thicknesses of continental sediments and small marine intercalations. Area of Olympic Mts. and western part of Coast Ranges at the south represented by long southward-extending peninsula composed of uplifted Metchosin lower Eocene volcanic materials with late Eocene Puget Gulf on east

TABLE IV—*Continued*

Age	*Formation*	
MIDDLE EOCENE	*Diastrophism*	North and south uplift of several thousand feet early Eocene volcanics in western Washington and Oregon into peninsula separating ocean on west from north-south marine trough on east. Area of Olympic Mts. forming part of peninsula but of no great relief
	Crescent	Tuffaceous shales and sandstones and interbedded submarine volcanic flows and tuffs. May have been directly connected with ocean. Exposed on north slope of Olympic Mts.
LOWER EOCENE	Metchosin volcanics	Two to five thousand feet of lava flows, tuffs, agglomerates, and intercalated black shales which accumulated on a differentially but continually subsiding coastal plain which involved entire area of Olympic Mts. as well as most of Washington and Oregon at least as far as eastern border of Cascade Mts. These volcanics now are steeply tilted forming a rim on north, east, and south sides of Olympic Mts. where they rest with profound unconformity on all older rocks. These lavas may be in part equivalent to Teannaway basalt of nearly equal thickness in east part of Cascade Mts. in Washington. Metchosin lavas extend south to north flanks of Klamath Mts. and north into Vancouver Island. They represent a volume of volcanic rock of about 21,600 square miles with average thickness of 3,000 feet accumulated mostly as submarine flows. Their importance as subsiding part of earth's crust as compared with later Columbia River lavas is generally not realized
Diastrophism and development of extensive coastal plain with surface of comparatively low relief		
EARLY PALEOCENE (?) TO JURASSIC (?)	Solduc	At least 8,000 feet of massive brownish gray arkosic sandstone exposed beneath Metchosin volcanics in higher northern part of Olympic Mountains as well as in west-central part. Other greatly indurated sandstones in southern part of mountains may be of equal age. Diagnostic fossils of these strata have not been obtained although middle Miocene fossils have been collected from lithologically similar rocks which probably are faulted down into Solduc formation. These beds may be continental in origin and range in age from Paleocene to Jurassic. Locally these rocks are greatly indurated and even metamorphosed. No plutonic rocks are known in Olympic Mts. but they may be present at no great depth, still uncovered by erosion. Lack of detailed geologic mapping in Olympics makes it impossible to separate pre-Tertiary rocks into distinct formations. Probable that no rocks older than Jurassic are present

and under different physical environments. Accordingly, a single formation may vary in thickness, lithologic character, and geologic age from one locality to another. The base of a formation at one place may correspond with the middle of the same formation at another locality where its deposition began somewhat later.

TABLE V
Correlation of Tertiary Formations

	WESTERN OREGON	WESTERN WASHINGTON	EASTERN WASHINGTON	EASTERN OREGON
PLEISTOCENE	Marine Terrace Deposits Development of Mt Hood etc	Marine Terrace Deposits Glacial Deposits Development Mt. Rainier, etc	Glacial and alluvial Deposits	Volcanics and Alluvial Deposits
PLIOCENE	Diastrophism EMPIRE	Diastrophism QUINAULT MONTESANO	Diastrophism Lava flows ELLENSBURG	Volcanics RATTLESNAKE DESCHUTES, DALLES and HOOD RIVER
MIOCENE	Diastrophism ASTORIA NYE SHALE	Diastrophism ASTORIA UPPER TWIN RIVER / SOOKE	LATAH COLUMBIA RIVER VOLCANICS YAKIMA BASALT UPPER KEECHELUS	MASCALL COLUMBIA RIVER LAVAS UPPER JOHN DAY EAGLE CREEK
OLIGOCENE	TUNNEL POINT SS / YAQUINA SS / EUGENE / PITTSBURG BLUFF BASSENDORF / TOLEDO / KEASEY / FISCHER	LOWER TWIN RIVER / BLAKELEY LINCOLN / Unamed shale / QUIMPER SS. KEASEY / LYRE / TOWNSEND SHALE	LOWER KEECHELUS	LOWER JOHN. DAY
EOCENE	ARAGO / COMSTOCK / SPENCER TYEE UMPQUA METCHOSIN VOLCANICS	COWLITZ / PUGET GROUP CRESCENT METCHOSIN VOLCANICS	ROSLYN / GUYE TEANNAWAY BASALT SWAUK	CLARNO

For similar reasons the top beds of the same formation may not everywhere be contemporaneous. The basins in which a single formation accumulated may have been intricately connected with one another or entirely separate, thus permitting contemporaneous but entirely different conditions of accumulation of sediments. The contained faunas were responsive to these varying physical environments. Consequently, the exact correlation of the different sections of the Tertiary formations in western Oregon and Washington is always open to revision. Table V shows a provisional correlation of the Tertiary formations of eastern and western Oregon and Washington. A possible correlation of these northern formations with those in the Coast Range of California is suggested in a recent paper prepared by a committee of the National Research Council and published by the Geological Society of America.[34]

In order to simplify the description of the different stratigraphic units of the Tertiary in western Oregon and Washington Table VI has been prepared with the formations arranged according to geologic age. All these materials accumulated on a floor which was at or just above sea-level at the beginning of the Tertiary. By the close of the Tertiary this floor with 20,000 feet of sediments on it had subsided sufficiently to permit locally the deposition of marine strata at the top. Subsidence was differential and intermittent with intervals of uplift and erosion. Folding at different times but mainly late in the middle Miocene and again at the close of the Pliocene has produced a structural pattern of anticlines and synclines involving all the Tertiary rocks from Vancouver Island southward to the Klamath Mountains. As the result of erosion great thicknesses of sediments have been removed from the axes of the folds but at no locality except in the Olympic Mountains have the rocks beneath the Tertiary been exposed. The geologist who investigates the possibilities for oil and gas in the Coast Ranges or the Puget Sound Basin and Willamette Valley must deal with these formations.

Conditions of Deposition of Tertiary Formations

All the available geological evidence in eastern and western Washington suggests that very early in Tertiary time there existed a vast coastal plain which may have extended from Idaho westward to and beyond the present coast. In places there may have been hilly and mountainous areas rising above its surface. The plain itself seems to have been somewhat undulating with several major east and west broad shallow synclinal downfolds within which large rivers flowed westward to the ocean. This plain had been carved into all the pre-Tertiary igneous, metamorphic and sedimentary rocks and the streams presumably adjusted themselves to the variations in hardness of the rocks over which they flowed. Early in the Eocene this plain began to subside differentially permitting oceanic waters to transgress eastward onto the broad shallow valleys in the plain. It is possible that the Swauk formation of eastern Washington may represent

[34] C. E. Weaver and Western Cenozoic Subcommittee," Correlation of the Marine Cenozoic Formations of Western North America," *Bull. Geol. Soc. America*, Vol. 55 (1944), pp. 569–98.

TABLE VI

Tertiary Formations in Coast Range of Oregon and Washington

		Washington	Oregon	
Pleistocene		Erosion, adjustment of drainage after withdrawal of glaciers from northern part of Puget trough. Local post-glacial uplift of 20 feet in Puget Sound area. Development of coastal terraces along ocean. Two advances of glacier from north, one branch passing out through Strait of Juan de Fuca, other south in Puget Sound Basin. Diastrophism at close of Pliocene and during early Pleistocene with uplift of Coast Range and downwarp of Puget trough. Olympic Mountains formed. Drowning of Pliocene valleys		
Upper Pliocene		Interval of erosion and probable deposition west of present coast of Oregon and Washington	Interval of erosion and probable deposition west of present coast of Oregon and Washington	
Lower and Middle Pliocene	Montesano Formation	Local downwarping of coastal plain in west parts of Coast Range in Washington, Oregon, and California. Transgression of marine water eastward into downwarps, forming embayments. Deposition of 4,000 feet of coarse brown sandstone with subordinate amounts of shale and conglomerate called Montesano formation. Well exposed in Grays Harbor region, Washington. Later folded into west-plunging syncline. Unconformable on older Tertiary formations	——?——?——?——?—— Deposition of 800 feet of massive sandstone in Coos Bay area, Oregon. Coos conglomerate forms lens in middle part of formation. Unconformable on Oligocene strata. Other sandstones on coast near Cape Blanco probably in part equivalent. Formation folded into northward-plunging syncline. Marine	Empire Formation
Upper Miocene		Strong diastrophism. Tertiary formations including Astoria compressed into northwest-trending folds, uplift, erosion, and production of coastal plain	Strong diastrophism. Tertiary formations including Astoria compressed into nearly north and south folds	
Middle Miocene	Astoria Formation	Transgression of sea over most of southwest Washington. Deposition of 1,500 to 5,000 feet of massive sandy clay shales with intercalations of submarine flows of basaltic lava which decrease in thickness west and increase east. East of lower Cowlitz River and in vicinity of Portland, formation is composed almost entirely of lava which probably corresponds with Yakima basalt of eastern Washington. Locally, Astoria is unconformable on Oligocene	Astoria formation well exposed on Oregon Coast north of Yaquina Bay, in Astoria and at many places in Coast Range south of Columbia River. Very thick flows of basalt make up half of formation. Basaltic flows, forming cliffs on north and south sides of lower Columbia River, composed of Astoria basalt. Astoria sandstone unconformable on upper Oligocene Nye shale just north of mouth of Yaquina River. Formation not recognized in Willamette Valley except near Portland	Astoria Formation
Lower Miocene		Probable minor uplift followed by erosion	Minor uplift followed by erosion	
Lower Miocene Upper Oligocene	Upper Twin River and Blakeley Formations	Section about 300 feet thick exposed in Chehalis Valley near Helsing Junction composed of sandstone and shale containing marine fossils. It crops over a very limited area and may be equivalent of both upper Twin River and type Blakeley formations ——?——?——?——?——?——	Nye formation consists of about 3,000 feet of massive to slightly stratified dark gray clay shale which rests conformably on Yaquina formation and is well exposed in sea cliffs on north side of Yaquina Bay and in ocean cliffs at Newport. Beds strike generally north and dip west	Nye Formation
Middle Oligocene	Lincoln Formation	Type section of Lincoln formation occurs in banks of Chehalis River between Centralia and Porter. Composed of 500 to 5,000 feet of brownish gray medium-grained shaly and tuffaceous sandstone with basal grits and conglomerates locally at base. Marine fossiliferous beds at Gries Ranch on Cowlitz River are probably representative of lower quarter of type section of Lincoln formation. Lincoln probably covered all southwestern Washington and is exposed in flanks of most of folds ——?——?——?——?——	Tunnel Point Sandstone 350 feet of massive brown sandstone, laminated ss., and subordinate amounts of interstratified sandy clay shale. Only at Coos Bay, in west limb of syncline. Marine Yaquina Formation Occurs at Yaquina Bay. 3,100 feet thick. Composed of coarse-grained brownish gray massive micaceous ss. Marine origin Eugene Formation At Eugene, Oregon. 5,000 to 7,000 feet ss., sandy shale, and conglomerate. Marine. Unconformable on Fisher formation Pittsburgh Bluff Fm. Massive gray medium-grained tuffaceous ss. and subordinate shale. Marine. In Columbia Co., Oregon	

TABLE VI—*Continued*

Age	Washington formation	Washington	Washington	Oregon	Oregon formation
Lower Oligocene Upper Eocene	Keasey Formation	Keasey formation composed of dark gray sandy tuffaceous shales best exposed in banks of Willipa River near Holcomb. Formation more limited in areal distribution than overlying Lincoln formation and rests unconformably on Metchosin volcanics with no known intervening strata of Cowlitz formation, thus suggesting local narrow straits formed across eroded and subsiding peninsula west of Cowlitz Gulf. Keasey beds in southwest Washington probably connected with those at type locality near Keasey in northwest Oregon ——?——?——?——?——?——		**Keasey Formation** Type section near Keasey, Columbia Co., Oregon. 500 to 1,000 feet thick. Sandy tuffaceous dark marine shale **Toledo Formation** Type section north side Yaquina Bay. 3,450 feet. Marine. Moderately fine-grained massive brownish gray to grayish brown sandy clay shales	
Upper Eocene				Fisher formation near Eugene, Oregon. 1,500 feet of rhyolitic tuff and agglomerate with nonmarine clays, sands, and gravels	Fisher Formation
Upper Eocene	Cowlitz Formation	Type section of Cowlitz exposed in banks of Olequah Creek and Cowlitz River where it is composed of 8,000 feet of marine grayish brown sandstone and sandy shale and lies in southwest limb of important northwest-southeast-trending syncline. Brackish-water beds present in middle of formation. Occurs in Puget trough from north of Chehalis south to Columbia River but thins west and finally disappears as it transgresses onto Metchosin basalts. Also occurs southeast of Seattle where it interfingers with continental Puget group	**Puget Group** Puget group consists of nearly 14,000 feet of thick beds of massive arkosic sandstone, massive shale, carbonaceous shales, and interstratified layers of shale and sandstone together with numerous coal and carbonaceous seams. Strata strongly compressed and faulted and mostly concealed beneath glacial materials. Well exposed in canyons of Green and Carbonado rivers southeast of Seattle. Pass unconformably beneath lavas of Cascade Mts. Occur east of Bellingham. Marine intercalations near Seattle	**Arago Formation** Type section in sea cliffs at Coos Bay. 8,400 feet. Marine. Alternating layers of brownish gray sandy clay shales, medium- and coarse-grained sandstones, shaly sandstones, and some layers of conglomerate. Lies in west limb of strongly folded syncline. Becomes coal-bearing east of Coos Bay. Widely exposed but exact distribution unknown. Probably equivalent in age to Cowlitz formation	
				Type section 2 miles southwest of Comstock, Oregon. 1,000 ft. of nonmarine micaceous sandstones, shaly siltstone, and light-colored tuffs. Unconformable on older strata and probably unconformable under Fisher formation	Comstock Formation
				Spencer occurs 10 miles southwest of Eugene and is composed of marine tuffaceous sandstone and shale	Spencer Formation
Lower and Middle Eocene	Crescent Formation	Type section of Crescent formation is on north side of Olympic Peninsula. Has not been recognized in southwestern Washington although some beds between Cowlitz formation and Metchosin volcanics may be its equivalent		Type formation occurs at Tyee Mountain northwest of Roseburg, Oregon. 5,000 feet of massive micaceous marine sandstone with subordinate amounts of shale	Tyee Formation
				Type section of Umpqua occurs along north Umpqua River 17 miles northeast of Roseburg. 4,400 feet of marine sandstone, shale, and conglomerate, resting on lava flows, tuffs, and sediments which possibly belong in formation. Well exposed farther north along axis of Coast Range	Umpqua Formation
Paleocene	Metchosin Formation	If all post-Metchosin sedimentary and volcanic formations were removed, surface rocks in southwestern Washington would be entirely composed of Metchosin volcanics. They extend up onto south slope of Olympic Mts., around its eastern northern margins and thence into type area on Vancouver Island. Lava flows, tuffs, and agglomerates of andesitic and basaltic composition. Largely submarine in origin and more than 4,000 feet thick. May correspond with Teannaway basalts of eastern slopes of Cascade Mountains in Washington		Metchosin volcanics at surface in Coast Range of western Oregon in axes of anticlinal folds where later Tertiary formations have been removed by erosion. Pillow structures and some interbedded red shales present but without fossils. These lavas occur on lower north slopes of Klamath Mountains. Described by Waters and Wells.* Unconformable on Cretaceous and older rocks * F. G. Wells and A. C. Waters, "Basaltic Rocks in the Umpqua Formation," *Bull. Geol. Soc. America*, Vol. 46 (1935), pp. 961–72.	
Pre-Tertiary		No definite information on age and lithologic character of formations underlying Metchosin volcanics in Coast Range of southwestern Washington and western Oregon. Greatly indurated sandstones come to surface from beneath Metchosin volcanics in south flanks of Olympic Mountains and sandstones, slates, metamorphic rocks, and intrusive igneous rocks underlie these volcanics in northern slopes of Klamath Mountains. Similar rocks may form floor on which Metchosin volcanics rest in intervening area. Possible that marine Jurassic and Cretaceous formations of east-central Oregon may extend westward beneath Cascade Mountains and parts of Coast Range in Oregon and Washington. Seas in which those sediments accumulated must have had direct communication with ocean. Connecting seaways may have been toward west or possibly south into Nevada and thence to ocean			

fresh water deposition in the landward end of these valleys and perhaps the Solduc formation of the Olympic Mountains may represent contemporaneous seaward deposition farther west although this formation is probably in part of continental origin. Both of these formations are folded and were eroded prior to

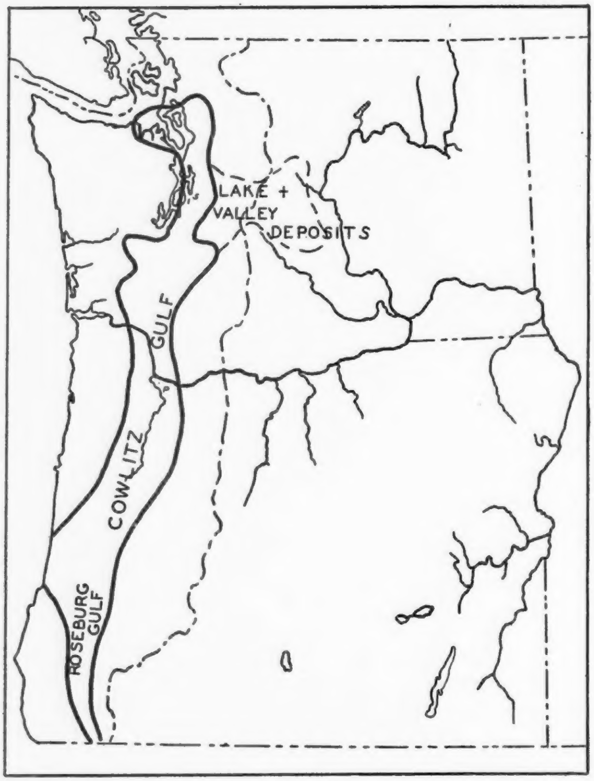

FIG. 2.—Probable Eocene embayment in Oregon and Washington during last quarter of Eocene time. West-east width of area mapped, approximately 360 miles.

the outpouring of the Teannaway volcanics in eastern Washington and the Metchosin volcanics in western Washington and Oregon.

IMPORTANCE OF METCHOSIN VOLCANICS

The type section of the Metchosin volcanics is on Vancouver Island where they originally were described by Clapp.[35] They range from 2,000 to 5,000 feet

[35] C. H. Clapp, "Preliminary Report on Southern Vancouver Island," *Canada Dept. Mines Geol. Survey Branch, Mem. 13* (1912), pp. 86–96.

thick and are of submarine origin as indicated by pillow structure and the occurrence of interbedded radiolarian cherts. They consist mainly of andesitic and basaltic flows together with tuffs, agglomerates, and numerous intrusive plugs suggesting their source from numerous small vents and dikes which came up through the subsiding coastal plain. These volcanics originaly formed one vast lava field extending from Vancouver Island southward to the north slope of the Klamath Mountains and eastward to the present site of the western foothills of the Cascade Mountains. By the close of Metchosin time there had accumulated a volume of volcanic material more than 500 miles long north and south by 150 miles wide east and west and with a probable minimum average thickness of at least 3,000 feet. The cubic content of this lava is as great as, if not larger than, that of the well known Columbia River lavas of eastern Oregon and Washington. Although these later flows are known to geologists throughout the world, very seldom have the Metchosin lavas[36] of early Eocene age been referred to in published reports. They rest on a plain which at the beginning of Metchosin time was above sea-level but which at the end had subsided into the crust to a depth equal to the thickness of the lavas. On these lavas rest perhaps 15,000 feet of marine Tertiary sediments, meaning that during the course of Tertiary time these lavas had subsided locally from 15,000 to 20,000 feet. Folding late in the middle Miocene and at the close of the Pliocene raised this thick sequence of lavas and sediments nearly to sea-level and erosion has removed the sediments from above the anticlinal axes in certain localities and cut down deeply into the lavas but not sufficiently to reach the base. In many of the synclinal folds the Metchosin volcanics are still many thousand feet beneath sea-level. These lavas are important from an economic standpoint because any well drilled into the overlying marine Tertiary sedimentary formations will ultimately penetrate the volcanic rocks. These in turn may rest on metamorphic rocks, granites, or pre-Tertiary sediments of unknown character. As before mentioned, the Metchosin volcanics have been removed by erosion from the central core of the Olympic Mountains where the basement rocks are exposed.

COWLITZ-ARAGO GULF

Near the close of Metchosin time crustal movements produced a nearly north-and-south axial upwarp with a corresponding parallel downwarp on the east. This resulted in a middle and late Eocene geography characterized by an elongate southward-projecting peninsula which extended from Vancouver Island to some unknown place west of Coos Bay, Oregon. The downfold along the east side of this peninsula was land-locked on the north end but open to the ocean at the south, and during the late Eocene formed an elongate inland gulf which may well be referred to as the Cowlitz-Arago gulf. It is possible that this late Eocene

[36] C. E. Weaver, "Tertiary Stratigraphy of Western Washington and Northwestern Oregon," *Univ. Washington Pub. Geol.*, Vol. 4 (1937), pp. 26–40.

———, "Metchosin Volcanic Rocks in Oregon and Washington," *Bull. Geol. Soc. America*, Vol. 50 (1939), p. 1961.

geographic pattern may have been somewhat similar to the present Peninsula of Lower California and Gulf of California. The Eocene peninsula included the western part of the present Coast Range of Washington and northwest Oregon together with an unknown area west of the present coast. The gulf occupied most of the area of the Puget Sound Basin and Willamette Valley, and the eastern half of the Coast Range. It is probable that the surface of the peninsula was not far above sea-level as only a small part of the Metchosin volcanics were removed by erosion during the Eocene.

During late Eocene there accumulated in the Washington part of the gulf nearly 8,000 feet of marine sediments which become progressively thinner toward the west as they lap onto the lavas in the eastern side of the peninsula. In the eastern side of the gulf were deposited 8,000 to 14,000 feet of brackish-water and fresh-water sediments containing commercial coal seams. Near Seattle these beds, named the Puget group, interfinger with the marine strata of the Cowlitz formation which filled the main part of the gulf. Subsidence of the broad shallow valleys extending in from the east seems to have been more pronounced along the eastern margin of the gulf in Washington than elsewhere, thus permitting thick deltaic deposits to accumulate locally and to keep pace with the amount of subsidence.

In western Oregon the peninsula may have veered more southwest so as to pass west of the present coast in the vicinity of Coos Bay, and here the gulf may have been nearly 100 miles wide. The southern end of the peninsula may have extended west of the present coast of northern California for an unknown distance toward the south. The marine sediments in the Coast Range east and southeast of Coos Bay began to accumulate earlier in the Eocene than farther north in Washington, as evidenced by the Umpqua, Tyee, and Arago formations. The Arago formation at Coos Bay is more than 8,000 feet thick and probably equivalent in age to the Cowlitz formation in Washington.

The marine invertebrate faunas of the Cowlitz and Arago formations are subtropical and somewhat similar to the upper Eocene Tejon faunas of southern California. If the interpretation given for the existence of a late Eocene peninsula and gulf is correct, it is possible that the occurrence of subtropical marine faunas as far north as Washington may be explained by the entrance of warm waters from the south, thus permitting the existence of such faunas far to the north. It is possible there may be sediments on the west side of the peninsula now deeply buried in the floor of the ocean which contain contemporaneous faunas with cooler-water genera. This statement is merely a suggestion.

The areal distribution and lithologic composition of the Oligocene formations in the Coast Range of Oregon and Washington suggest that early in the Oligocene parts of the peninsula began to break down, forming straits or channels which permitted oceanic waters to gain access to the gulf. Some of the early Oligocene sediments rest directly on the Metchosin volcanics toward the west, but toward the east they extend over onto the sedimentary late Eocene formations which were deposited in the gulf. In the Coos Bay region of Oregon the

peninsula was west of the present coast and the Oligocene sediments rest on the Arago formation. Later in the Eocene the surface of the peninsula seems to have passed completely below sea-level and the western part of Oregon and Washington subsided sufficiently to permit the deposition of nearly 8,000 feet of marine sandstone and shale. It should be noted here that the terms Oligocene and Miocene are being used in the older sense based on the interpretation of mollusks and other megafaunas and not on the later classifications based on *Foraminifera.* Early in the Miocene local minor uplifts caused the sea to regress for the most part west of the present coast with minor erosion of the smaller upwarps.

During the middle Miocene local areas of subsidence allowed the sea again to transgress eastward over parts of the Coast Range, more extensively in southwest Washington than in Oregon. There were deposited in these seas more than 4,000 feet of marine sandstone with subordinate amounts of shale. These sediments are called the Astoria formation. During their deposition great quantities of lava were coming to the surface through numerous vents and fissures especially in the Columbia Plateau, and in the area of the Cascade Mountains which in southern Washington and Oregon was probably near sea-level. These flows gradually feathered out toward the west but north of Portland they form about 50 per cent of the Astoria formation. Farther west the number of flows as well as their thickness diminishes. Only two are known in the region of Grays Harbor. The Astoria formation is not known to occur at the surface in the Puget Sound Basin.

Late Middle Miocene Diastrophism

After the deposition of the Astoria formation the western areas of Washington and much of Oregon were subjected to crustal disturbances with forces acting from the northeast toward the southwest. As a result the pre-Tertiary igneous and metamorphic rocks along with the overlying great thickness of Tertiary lavas and marine sediments were folded into northwest and southeast-trending major anticlines and synclines.[37] Those which formed the parallel Vancouver Island-San Juan Islands-northern Cascade upwarp and the Olympic-Newcastle Hills-Cascade upwarp have already been referred to. Farther south in southwestern Washington similar but less important folds were developed. In northwestern Oregon these northwest-trending folds gradually become nearly north and south, and such folds characterize the Coast Range of that region. During late Miocene time the Coast Range and Cascade Mountains and intervening Puget Sound-Willamette trough as such did not exist. In other words, if a person during late Miocene time had desired to make the trip from Vancouver, Canada, to Portland, Oregon, it would have been necessary to climb over the mountain range where the San Juan Islands now exist and then to have descended and crossed a broad structural valley to a point not far north of Seattle. Then it would

[37] C. E. Weaver, "Tertiary Stratigraphy of Western Washington and Northwestern Oregon," *Univ. Washington Pub. Geol.*, Vol. 4 (1937), pp. 198–99, 205.

have been necessary to climb over another high mountain ridge which extended across the present Puget Sound Basin. The remnants of this range are still represented by high hills west of Bremerton and by the upturned edges of 8,000 feet of Oligocene sediments exposed along the shores of the channel leading to the Navy Yard. Beyond, toward Portland, he would be confronted with numerous smaller topographic features all of structural origin.

During the Pliocene these mountains were undergoing vigorous erosion and minor structural deformation. East of the ocean southward to California coastal plains were developed which locally were slightly downwarped. The oceanic waters transgressed eastward into these slowly and differentially subsiding sags and formed irregular-shaped bays and small gulfs. The seas did not all come in contemporaneously but by the close of the Pliocene several thousand feet of marine sandstones and shales had accumulated. These deposits are named the Quinault and Montesano formations in Washington, the Empire formation in southwest Oregon, and the Wildcat series in northwest California, and all were folded during the late Pliocene-early Pleistocene diastrophism.

Origin of Coast Range and Cascade Mountains

The Coast Range and Cascade Mountains were produced at the close of the Pliocene as the result of crustal disturbances which affected the entire west coast of North America. The present topographic features of western Oregon and Washington were largely produced at this time but somewhat modified by glacial action and erosion during the Pleistocene. The Cascade Mountains were in process of development during late Tertiary time but the uplift was greatly accelerated at the close of the Pliocene. At several points along the range volcanic products came to the surface and built such cones as Baker, Rainier, St. Helens, Adams, Hood, and several smaller cones farther south in Oregon. The widespread changes in topography and climate following these crustal disturbances accompanied the glacial epoch. Numerous valley glaciers from the mainland of British Columbia entered the topographic depression on the northeast side of Vancouver Island forming a vast tongue of ice which moved south into the Puget Sound Basin. It split into two prongs, one of which moved westward through the Strait of Juan de Fuca, and the other due south to a position near Olympia, Washington. During the Pliocene two major north-and-south erosional valleys were formed in the site of Puget Sound Basin and later in the Pliocene through each of these, great lobes of ice ploughed their way. Two definite glacial epochs have been described in this area,[38] and one other has been suggested. The ice was sufficiently thick to push its way up into the valleys on the east side of the Olympic Mountains and leave terminal moraines at altitudes of 2,500 feet above sea-level. After the re-

[38] Bailey Willis, "Description of the Tacoma Quadrangle," *U. S. Geol. Survey Geol. Atlas Folio 54* (1899).
J H. Bretz, "Glaciation of the Puget Sound Basin," *Washington Geol. Survey Bull. 8* (1913), pp. 9–244.

treat of the last ice sheet toward the north the entire Puget Sound Basin was left covered with great thicknesses of glacial materials with occasional knobs of bed rock projecting above it. The largest of these is represented by the Wildcat Hills in the middle of the basin west of Bremerton. The floors of Hood Canal and Admiralty inlets are now below sea-level but represent the sites of late Pliocene erosional valleys.

Possibilities for the Occurrence of Oil and Gas

Any consideration of the possible commercial occurrence of oil or gas in Oregon and Washington involves a study of the areal distribution, lithologic character, variations in thickness, and structure of the formations already described. It may be well to evaluate some of the available data in terms of geographic areas such as the Okanogan Highlands, Blue Mountains, Columbia Plateau, Malheur Plateau of southeastern Oregon, northern Cascade Mountains, southern Cascade Mountains of Washington and Oregon, Olympic Mountains, Puget Sound Basin, Willamette Basin, Klamath Mountains, and the Coast Range between the Olympic and Klamath mountains.

An areal geologic map of the Okanogan Highlands would show formations consisting of crystalline schists, crystalline limestones, quartzites, and slates, together with granites and other allied igneous rocks overlain here and there with various sized patches of Tertiary volcanic materials and some lacustrine and fluviatile sediments. The granites and other igneous rocks can not be considered as possible sources of oil or gas. The porosity of the metamorphic rocks is extremely low and the physical and chemical changes to which they have been subjected must have destroyed any pre-existing oil or gas which might have existed within them. The Tertiary continental deposits are largely fluviatile and the only source from which gas could originate would be small quantities of vegetation which may have accumulated intermittently in local ponds of water. It would seem as though this material would be insufficient to give rise to any commercial quantities of gas.

The northeastern part of the Blue Mountains is geologically similar to the Okanogan Highlands and the same conclusions would apply to the occurrence of oil or gas in that region. However, the erosional windows in the southwest extension of the Blue Mountains indicate a basement composed of 16,000 feet of strongly folded Jurassic sediments which consist of non-metamorphosed but greatly indurated shales, limestones, and sandstones. These sediments probably do not form the basement rocks very far north or south of the area where exposed and should not be considered as widely spread beneath the Tertiary lavas. Although indications of oil and gas have not been reported from these rocks, it is probable that as the world oil supply becomes scarcer they may be geologically examined.

The volcanic materials in the Columbia Plateau are in places more than 4,000 feet thick. From evidence around the east, north, and northwest margins of the

lavas, the basement rocks are mainly granite and intensely metamorphosed sedimentary rocks similar to those in the Okanogan Highlands and the northeastern part of the Blue Mountains. It appears certain that no marine Tertiary rocks occur at any place east of the Cascade Mountains. Sandstones of the Swauk formation from the eastern side of the Cascade Mountains in Washington do pass beneath the eastern margin of the Columbia lavas, but only for a short distance. It is questionable whether these sandstones can be considered as source beds for oil as they are in part fluviatile in origin. The overlying Columbia River lavas are folded into shallow anticlines and synclines and the same is true of the Swauk sandstones but the eroded anticlinal folds in the latter have no relation to the folds in the lavas above. Therefore, a well drilled on a surface anticline in the lavas might enter a synclinal fold in the Swauk sandstones beneath. All the available evidence suggests that the basement rocks beneath the Columbia River lavas can not be considered as source beds for oil and probably not for gas.

A well drilled into the lavas on an anticline southeast of Yakima for water encountered methane gas. Later several wells were drilled to depths of more than 2,000 feet through dense lava flows and intervening vesicular lavas and some fresh-water sediments which probably were deposited intermittently in ponded streams caused by laval dams. The gas pressure in these wells was always low, and at the present time the production of gas has stopped. For a number of years sufficient quantities were produced to supply the needs of several small towns in the lower Yakima Valley. The source of this gas is unknown, but it probably originated from small local accumulations of vegetation which had collected in ponded water during intermission between lava flows. All the available geologic evidence in the Columbia Plateau suggests that commercial quantities of oil are absent and probably the same is true for gas. Any attempt to drill in this area means that at least 4,000 feet of hard lava must be penetrated with the probability of encountering granite or metamorphic rock beneath.

The Malheur Plateau of southeastern Oregon presents the same problem as the Columbia Plateau. The lavas are fully as thick as may be seen in the escarpments of Steens Mountain near the Nevada line. It is possible that the underlying basement rocks in this area may be granite, schist, quartzite, and possibly some of the Paleozoic sedimentary rocks known to occur in the Basin Range mountains of Nevada.

As already mentioned the rocks of the northern half of the Cascade Mountains in Washington are entirely different from those of the Cascades farther south. They consist of granite and other associated plutonic rocks, thoroughly metamorphosed sediments and volcanic materials and down-faulted blocks of Tertiary lava and continental sediments. Near the Canadian boundary there do occur greatly indurated marine sediments of Mesozoic age whose geologic structures are not well known. No indications of oil or gas have been reported from these rocks but it is probable they may be examined geologically from time to time. These formations pass beneath the thick covering of Tertiary lavas which make up the

Cascade Mountains south of Snoqualmie Pass in Washington. Any attempt to drill in this southern part of the Cascade Mountains means penetrating several thousand feet of lava with no information concerning the nature of the basement rocks upon which the lavas rest.

The Klamath Mountains in southwestern Oregon like those of the northern Cascades and the Okanogan Highlands are composed of granites, metamorphic rocks, and many intrusive igneous rocks all of which have been intricately deformed. Arkosic sandstones largely equivalent to the Franciscan formation are folded and faulted into the older complex of the northern part of these mountains. In addition there occur relatively thin sections of late Jurassic and Cretaceous sediments which rest unconformably on the older rocks and which continue north beneath the thick Tertiary sequence. There is no information on the northward extent of these sediments beneath the Tertiary rocks of the Coast Range. An interpretation of the geological conditions in the Klamath Mountains for the occurrence of commercial quantities of oil and gas would be the same as for the Okanogan Highlands.

There remain the Coast Range from the Klamath Mountains north to Vancouver Island, the Puget Sound Basin, and Willamette Valley. This area includes about 20 per cent of Oregon and Washington. It contains rocks and structures locally which are worthy of consideration as possible sources of oil and gas, although there is no evidence to show conclusively that commercial quantities of such materials are actually present.

Some of the indications of oil and gas in the Coast Range consist of very small oil seepages or escaping odors of gas from the rocks. A very strong odor of gas may be observed at low tide on the beach between Pysht and Twin Rivers on the north side of the Olympic Peninsula. The exposed rocks are folded and faulted shaly sandstones of Oligocene age. The sandstones and shales exposed in the sea cliffs on the western side of the Olympic Peninsula are strongly folded and at several places yield a distinct odor of oil. Just north of the mouth of Hoh River and a short distance east of the coast a shaft was sunk to a depth of 20 feet about 40 years ago. In 1911 there accumulated on its floor about one half pint of light-colored, low-gravity oil each morning. Other seepages have been reported at several places nearby. The rocks involved are largely sandstones of the Astoria formation. In 1912 certain Oligocene shales, near the mouth of Bear Creek just north of the mouth of Columbia River, when freshly broken yielded a distinct odor of oil. Some of this shale when heated would burn with a flame for a few seconds.

Thick diatomaceous light-colored shales such as occur in the oil fields of southern California are unknown in Oregon and Washington. The Eocene sediments are prevailingly sandy. The Oligocene formations are rather massive shaly sandstones and contain large quantities of tuffaceous material. The shaly content is more prominent westward toward the ocean. The Astoria beds are ordinarily sandy although sandy shales do occur in places and one type grades

into the other laterally. The Montesano and Empire formations of Pliocene age are marine, but commonly composed of sandstone. The present shore line of both Oregon and Washington has been receding eastward for a long time, and the upturned edges of the formations in the sea cliffs extend westward for an unknown distance beneath the floor of the ocean. It is possible that the sandstones gradually become more shaly in the ocean floor west of the coast so as to form source beds. If so, the small seeps inland on the Olympic Peninsula may be the result of slow migration into the sandstone.

The thick alternating sandstones and shales of the Puget group along the western foothills of the Cascade Mountains in Washington contain many commercial coal seams with some associated gas. These continental beds interfinger with the marine Eocene sediments toward the west. There is a possibility that some of the more shaly parts of the marine strata may be source beds and that some of the hydrocarbons have migrated into the sandstones of the Puget group. The latter are strongly folded and cut by numerous faults. Except in the region southeast of Bellingham surface exposures are confined largely to river canyons; the intervening areas being thickly veneered with glacial deposits. Gas seepages such as that at the Flaming Geyser east of Tacoma are probably associated with coal seams.

The area northwest of Bellingham, Washington, is a part of the flood plain near the mouth of Frasier River. Its surface is only slightly above sea-level. The rocks below consist of about 300 feet of glacial material overlain with alluvium. These glacial deposits rest on a surface carved out of folded sandstones and shales which have been considered a part of the Puget group, but may, toward the west where buried, pass into the upper part of the Cretaceous Nanaimo series exposed on the northern border of the San Juan Islands and on Vancouver Island. In 1937, several wells were drilled into the lowest part of the glacial deposits and for a few months produced some gas, but all of these wells were soon abandoned. They can not be considered as having been commercial producers. The structures in the underlying continental beds are unknown.

During the past 50 years more than 40 wells have been drilled in the Pacific Northwest and, with the exception of the temporary production of gas in the Rattlesnake Hills in southeastern Washington, none of these was of commercial type. Some of the wells were drilled with geologic control; others were not. Lack of financial backing prevented certain wells from being drilled sufficiently deep to constitute a test.

The Tertiary formations in western Oregon and Washington are of the same geologic age as those which produce oil and gas in California but possibly the environmental conditions under which they accumulated were somewhat different. All the marine Tertiary sediments are folded, but in general not complexly faulted. Erosion has carved deeply into some of the folds and in many places the entire sedimentary sequence has been removed, leaving the basal Metchosin volcanics at the surface.

The geologist who considers an investigation of the Coast Range of Oregon and Washington, with the exception of the Olympic and Klamath mountains, is confronted with the Tertiary sequence of formations already described. At no locality will there be a complete section represented. The lithologic character and thickness of any given formation will vary greatly from one locality to another. Any well drilled through the Tertiary marine sediments will ultimately enter several thousand feet of lower Eocene volcanics which in turn rest on a basement composed of unknown rocks. The main problem is to determine the structure and the probable lithologic character of the stratigraphic sequence at the place where drilling is decided upon, and then to regard the venture as a test to determine the ability of the rocks penetrated to furnish commercial quantities of oil or gas.

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SUBSURFACE LOWER CRETACEOUS FORMATIONS OF SOUTH TEXAS[1]

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Washington, D. C.

ABSTRACT

Evidence is presented: (1) that the Hosston and Sligo formations extend from eastern to southern Texas, that they do not crop out on the Coastal Plain, and that they represent the Neocomian and lower Aptian, respectively; (2) that the Travis Peak formation of the outcrop area is represented in the subsurface by a shaly sequence, herein named the Pearsall formation, which includes basally the Pine Island shale member, medially the Cow Creek limestone member, and at the top the Hensell shale member; (3) that the tops of (a) the Cow Creek limestone member of the Travis Peak and the Pearsall formations, (b) the James limestone, and (c) the Dierks limestone mark approximately the Aptian-Albian boundary; (4) that the Ultima Thule gravel member of the Holly Creek formation of Arkansas, which passes basinward into the basal part of the unit known informally as the Hill sandy lentil of the Rodessa, may mark the position of a minor disconformity, and is probably correlative with the conglomeratic beds at the top of the Hensell sand member of the Travis Peak formation; (5) that the Glen Rose formation of South Texas passes northward in the subsurface into the Paluxy, Mooringsport, and Ferry Lake formations and the upper part of the Rodessa formation; (6) that some silty shaly beds at the top of the subsurface Glen Rose limestone of South Texas are probably equivalent to the Paluxy sand of the outcrop; (7) that the Edwards and Comanche Peak limestone of South Texas are considerably thicker than equivalent beds in East Texas; (8) that the surface of the Edwards limestone in the area of the San Marcos arch was subjected to considerable erosion prior to Fort Worth time; (9) that the Kiamichi formation is represented in South Texas by a sequence of black limestone and shale containing considerable anhydrite and, locally, salt; (10) that the Kiamichi formation throughout most of the subsurface of South Texas grades into the overlying Georgetown limestone, but near its northern boundary pinches out in a short distance and is overlapped disconformably by the Georgetown; (11) that the surface and subsurface Georgetown limestone of South Texas west of Uvalde County grades into a thicker rudistid facies.

INTRODUCTION

This report describes and interprets the regional stratigraphy of the Lower Cretaceous formations of South Texas and discusses the correlation of these formations with equivalent rock units in northern Mexico and eastern Texas. Although many of the conclusions presented herein have been published in *Preliminary Charts 3* and *8* of the United States Geological Survey's Oil and Gas Investigation Series, it is felt that a more complete discussion of the facts from which those conclusions were drawn will afford those interested in the stratigraphy of these formations a more adequate basis for appraisal of the interpretations made. As most of the Lower Cretaceous formations that produce oil in East Texas have not been adequately tested in South Texas, their proper correlation and identification in South Texas seem essential for future oil exploration. In South Texas the beds near the contact of the Hosston and Sligo formations consist of alternating limestones and sandstones that appear to be favorable for oil accumulation and exploration. The Cow Creek limestone member of the Pearsall formation is similar lithologically and stratigraphically to the James limestone of the Arkansas-Louisiana-East Texas area and has not been adequately tested

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for its oil possibilities. Also, testing of the deeply buried Jurassic beds should be less expensive and more efficient when the characteristics of the Hosston formation are thoroughly understood.

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Stratigraphic Summary

The Lower Cretaceous formations of South Texas range in thickness from a minimum of about 950 feet on the outcrop to at least 5,275 feet in the subsurface (Tables II and III). Undoubtedly, deeper drilling in certain areas will reveal even greater thicknesses. Gradual changes in facies from a sequence typical of East Texas to a sequence typical of northern Mexico occur in most of the formations as they are traced southward along the eastern margin of the Central Mineral region and thence westward along its southern margin. Evidently the Central Mineral region was the main source of clastic sediments, but the San Marcos and Edwards arches had considerable control over the distribution of sediments. A flexure along the site of the Balcones fault zone greatly influenced sedimentation during Neocomian and lower Aptian time, as the Hosston and Sligo formations thin markedly in the area of the fault zone and apparently never extended much farther inland. Brief descriptions of the formations from oldest to youngest are given in the following paragraphs.

The Hosston formation of South Texas (Table I, Figs. 2–5) ranges in thickness from a feather-edge to at least 1,100 feet. In the thickest known sections, its upper 300 to 500 feet consists mainly of dark calcareous limestone interbedded with some dark shale and gray sandstone, its middle 300 to 400 feet consists mainly of red sandstone and shale, and its basal part consists of varicolored conglomerate in a matrix of red sandstone and shale. It differs from the Hosston formation of East Texas by a nearly complete lack of red beds in its upper few hundred feet and by being much more calcareous. It rests unconformably on

TABLE I

Correlation of Lower Cretaceous Formations of Coastal Plain of Arkansas, Louisiana, and Texas

	European Equivalents		Gulf Coast and Mexican Equivalents		Outcrops in Southern Arkansas	Subsurface of Ark.-La.-East Texas	Outcrops in North-Central Texas	Outcrops Central Mineral Region	Subsurface of South Texas	Sierra del Burro of Northern Coahuila	Southern Quitman Mtns. Hudspeth Co. Texas	Cuchillo Parado Area Northeastern Chihuahua	Santa Elena Area of Eastern Chihuahua	Sierra de Santa Ana Southwestern Coahuila	Mountains East-Central Coahuila	Sierra de Parras of Southern Coahuila
Upper Cretaceous		Lower Cenomanian	Comanche Series	Washita Group		Unnamed beds ? Buda Ls. Grayson Sh.	? Buda Ls. Grayson Sh.	? Buda Ls. Grayson Sh.	? Buda Ls. Grayson Sh.	? Buda Ls. Grayson Sh.	? Buda Ls. Grayson Sh.	? Buda Ls. Grayson Sh.	Limestone and Shale	Lower Member of Indidura Formation	Cuesta del Cura Limestone	Cuesta del Cura Limestone
Lower Cretaceous	Albian	Upper Albian	Comanche Series	Washita Group	Absent	Georgetown Limestone	Main Street Ls. Pawpaw Fm. Weno Ls. Denton Clay Fort Worth Ls. Duck Creek Ls.	Georgetown Limestone	Georgetown Limestone	Georgetown Limestone	Georgetown Limestone	Aurora Limestone				
Lower Cretaceous	Albian	Middle Albian	Comanche Series	Fredericksburg Group	Kiamichi Fm. Goodland Limestone Not identified	Kiamichi Fm. Goodland Limestone Walnut Clay	Kiamichi Fm. Edwards Ls. Comanche Peak Ls Walnut Clay	Kiamichi F. Edwards Ls. ? Comanche Peak Ls & Walnut Clay	Kiamichi F. Edwards Ls. ? Comanche Peak Ls	Kiamichi F. Edwards Ls. ? Comanche Peak Ls	Kiamichi Fm. Edwards Finlay Limestone	Kiamichi F. ?	Kiamichi Fm(?) Aurora Limestone	Aurora Limestone	? Aurora Limestone	Aurora Limestone
Lower Cretaceous	Albian	Middle Albian / Lower Albian	Comanche Series	Trinity Group	Paluxy Sand De Queen Limestone ? Holly Creek Fm.*	Paluxy Form. Upper / Lower Mooringsport F. Ferry Lake Anhydrite Rodessa Fm. ?	Paluxy Sand Glen Rose Ls. Basal Sand	Glen Rose Limestone	Glen Rose Limestone	Glen Rose Limestone	Glen Rose Formation Quitman Bed of Taff	Glen Rose Limestone		? Cuchillo Formation: Gypsum, Dolomite, Limestone; Massive Limestone		
Lower Cretaceous	Aptian	Gargasian	Comanche Series	Trinity Group	Dierks Ls. Delight Sand Pike Gravel	James Ls. Pine Island Shale		Travis Peak F.: Hensell Sand Mem.; Cow Creek Ls. Mem.; Sycamore Sand of Hill	Pearsall Fm.: Hensell Sh. Mem.; Cow Creek Ls. Mem.; Pine Island Sh. Mem.	Shaly Limestone and Shale	? (Upper Part) Mountain Bed of Taff (Equals Yucca Bed of Taff)	? Cuchillo Formation: Shale and Shaly Limestone	? Cuchillo Formation: Shaly Limestone and Shale	Cuchillo Formation: Shale, Sandstone and Conglomerate	La Peña Fm. Cuchillo Fm.	La Peña Formation: Upper Member
Lower Cretaceous	Aptian	Bedoulian	Coahuila Series of Mexico	Nuevo León Group of Mexico		Sligo Formation			Sligo Formation	Not exposed		Cuchillo Formation: Gypsum, Salt and Shale	Cuchillo Formation: Gypsum, Shale and Some Limestone		? Patula Arkose ? La Mula Shale	La Peña Formation: Lower Member
Lower Cretaceous	Neocomian	Barremian	Coahuila Series of Mexico	Nuevo León Group of Mexico		Hosston Formation			Hosston Formation	Not exposed	? (Lower Part) Mountain Bed of Taff (Equals Las Vigas Fm.)	? Las Vigas Formation	Not exposed		? Padilla Limestone	? Parritas Fm. Cupido Ls
Lower Cretaceous	Neocomian	Hauterivian	Coahuila Series of Mexico	Durango Group of Mexico		Hosston Formation			Hosston Formation	Not exposed		Las Vigas Formation	Not exposed		Barril Viejo Shale San Marcos Arkose	Las Vigas Fm. Taraises Fm.: Upper Member
Lower Cretaceous	Neocomian	Valanginian	Coahuila Series of Mexico	Durango Group of Mexico						Not exposed		Las Vigas Formation	Not exposed		Menchaca Limestone ? Unnamed Shale	Taraises Fm.: Lower Member
Lower Cretaceous	Neocomian	Berriasian	Coahuila Series of Mexico	Durango Group of Mexico						Not exposed	? Not exposed	Las Vigas Formation	Not exposed		? Not identified	?
					Pennsylvanian	Jurassic	Pennsylvanian	Pennsylvanian				Jurassic		Permian	Jurassic	Jurassic

* Ultima Thule Gravel Member

Jurassic, Paleozoic, and possibly pre-Cambrian rocks and grades upward within a few feet into the dolomitic limestones of the Sligo formation. Its age must be mainly Neocomian.

The Sligo formation of South Texas (Tables I–III) ranges in thickness from 210 to 750 feet, consists mostly of gray to brown limestone beds separated by considerable black shale, but contains some dolomitic beds and white anhydrite in its lower three-fourths. The contact with the overlying Pearsall formation is very abrupt, suggesting a sudden change in sedimentation. A lower Aptian age for the Sligo formation is indicated by its position beneath the Pine Island shale member of the Pearsall formation of upper Aptian age and by its similarity to lower Aptian beds in northern Mexico.

The Pearsall formation (Tables I and II) consists dominantly of shaly beds, ranges from 170 to 570 feet, or more, in thickness (Table III), and comprises three members (Figs. 2–5). The Pine Island shale member at the base is very similar to the Pine Island shale of the Arkansas-Louisiana-East Texas area. The Cow Creek limestone member in the middle is similar to the Cow Creek limestone member of the Travis Peak at the outcrop in the Central Mineral region and to the James and Dierks limestones of the Arkansas-Louisiana-East Texas area. The Hensell shale member at the top contains much more limestone than the Pine Island shale member and in some sections contains sandstone. The Pine Island shale and Cow Creek limestone members are definitely of upper Aptian age, but the Hensell shale member is probably mainly of basal Albian age.

The Glen Rose limestone in the subsurface of South Texas thickens basinward from 460 feet to more than 1,840 feet (Table III). It consists of a monotonous sequence of hard, gray, tan, and brown limestone, but commonly contains shaly beds at the top and bottom. Small amounts of anhydrite occur throughout. Its boundaries appear to be conformable, although disconformities may exist in marginal areas. Toward the outcrop the formation becomes sandy, especially at its top and bottom (Figs. 2 and 5). The age of the Glen Rose limestone represents lower Albian and part of middle Albian. North of Robertson County in East Texas, the Glen Rose limestone passes into four lithologic units (Fig. 3), which, from top to bottom, include the Paluxy formation, the Mooringsport formation, the Ferry Lake anhydrite, and the upper part of the Rodessa formation. This sequence below the Paluxy formation passes northeastward into the DeQueen limestone at the outcrop in southern Arkansas.

The Edwards and Comanche Peak limestones in the subsurface of South Texas are generally combined under the term Edwards limestone (Tables II and III). The limestones thicken basinward (Figs. 2–5) from about 200 to 825 feet and consist mainly of hard, dense to coarsely crystalline, gray to brownish black limestone. Some layers are soft, and some are very porous. Dolomite and anhydrite are common, particularly in the lower part of the formation. Chert occurs in some beds. The contact with the overlying Kiamichi formation is generally sharp but apparently conformable. However, in the deeper part of the Rio Grande

TABLE II

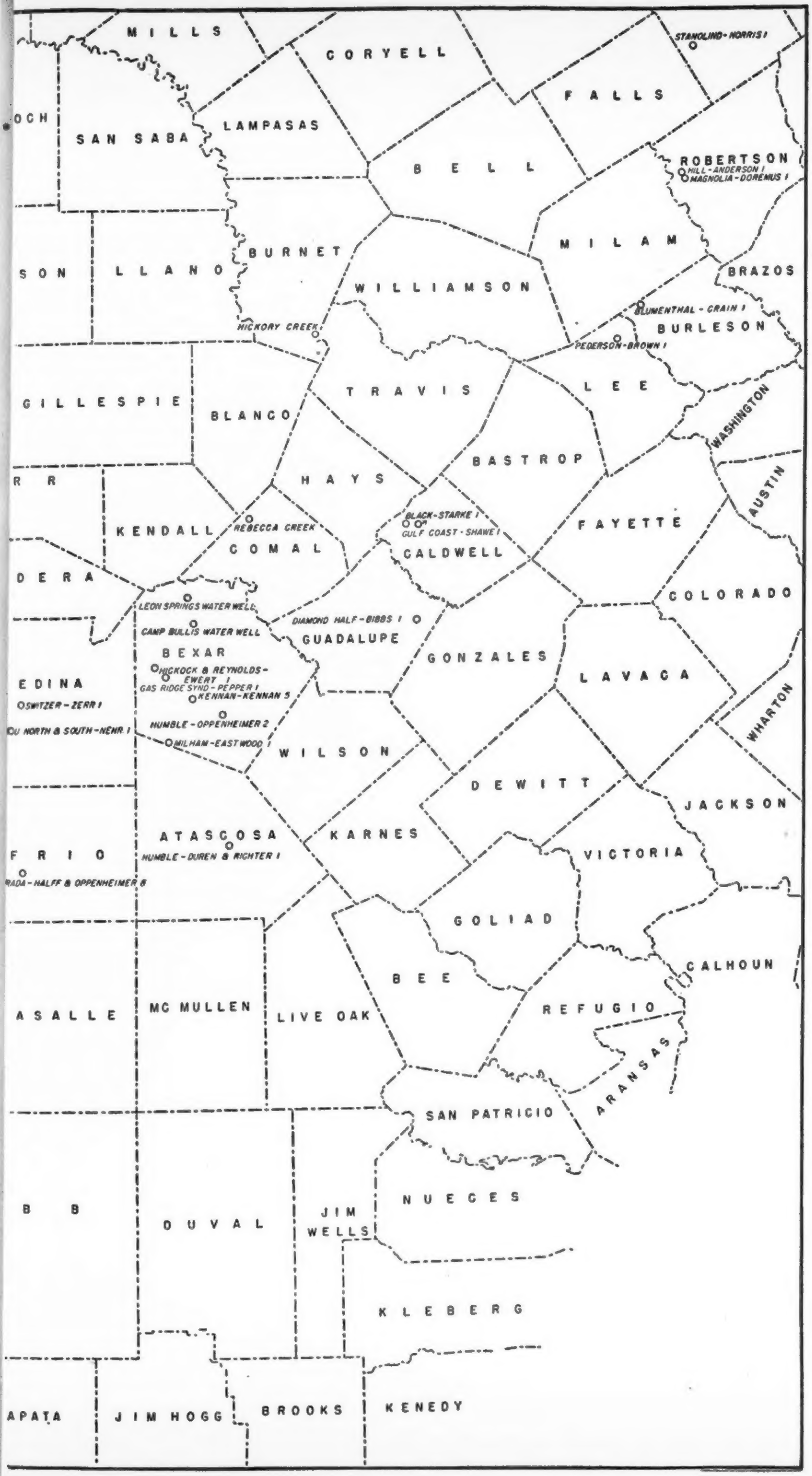
Formation Tops in Comanche and Older Rocks in South Texas and Mexico

COMPANY	WELL	APPROXIMATE LOCATION	COUNTY OR STATE	ELEVATION	BUDA LIMESTONE	GRAYSON SHALE	GEORGETOWN LIMESTONE
MAGNOLIA PET	DOREMUS NO 1	ABOUT 1¼ MILES NW. OF CALVERT	ROBERTSON	333	4292	4350	4423
BLUMENTHAL (RED BANK)	CRAIN NO. 1	ABOUT 12 MILES NW. OF CALDWELL	BURLESON	550	5932	5997	6040
SHELL (PEDERSON)	BROWN NO. 1	5 MILES S. OF N. CORNER OF COUNTY	LEE	447	6070?	?	6155 or 6200
JOHN BLACK	STARKE NO. 1	ABOUT 3 MILES EAST OF MAXWELL	CALDWELL	577	1630	1680	1730
GULF COAST OIL	SHAWE NO 1	½ MILE NORTH OF MAXWELL	CALDWELL	635	1070	1120	1170
DIAMOND HALF OIL	BIBBS NO. 1	13 MILES E.-NE. OF SEGUIN	GUADALUPE	509	2705	FAULTED OUT	FAULTED OUT
HICKOCK AND REYNOLDS	EWERT NO. 1	19 MILES W.-NW. OF SAN ANTONIO	BEXAR	995	175	242	307
GAS RIDGE SYND.	PEPPER NO. 1	14 MILES WEST OF SAN ANTONIO	BEXAR	950	328	380	420
KENNAN	KENNAN NO. 5	7 MILES SOUTHWEST OF SAN ANTONIO	BEXAR	680	1084	1135	1193
HUMBLE OIL & REF.	OPPENHEIMER NO. 2	6 MILES SOUTH OF SAN ANTONIO	BEXAR	607	1415	1505	1555
MILHAM (BALLARD & UNDERWOOD	EASTWOOD NO. 1	18 MILES SOUTHWEST OF SAN ANTONIO	BEXAR	647	2053	2154	2232
U. S. WATER WELL	CAMP BULLIS	14 MILES NORTHWEST OF SAN ANTONIO	BEXAR	1050	ON SURFACE	14	50
U. S. WATER WELL	LEON SPRINGS	2 MILES NORTHEAST OF LEON SPRINGS	BEXAR	1156			
HUMBLE OIL & REF.	DUREN & RICHTER NO. 1	26 MILES FR. S. AND 32 MILES FR. W. COUNTY LINE	ATASCOSA	402	7450?	FAULTED	FAULTED
SWITZER	ZERR NO. 1	19 MILES FROM N. AND 27 MILES FR. E. COUNTY LINE	MEDINA	927	648	792?	800?
UNITED NORTH & SOUTH	NEHR NO. 1	25 MILES FR. N. AND 29 MILES FR. E. COUNTY LINE	MEDINA	841	893	930	992
AMERADA	HALFF & OPPENHEIMER NO. 8	ABOUT 10 MILES SW. OF PEARSALL	FRIO	569	5885	6005	6100
AMERADA	HALFF & OPPENHEIMER NO. 2	SAME	FRIO	540	5660	5810	5900
PURE OIL	SMYTH NO. 1	NEAR W. LINE & 4 MILES FR. S. LINE OF COUNTY	UVALDE	1160	1610	1710	1835
HUMBLE OIL & REF.	ANDERSON NO. 1	1 MILE EAST OF UVALDE	UVALDE	961			
PHANTOM OIL	CLOUDT NO. 1	9 MILES FR. N. AND 2 MI. FR. W. COUNTY LINE	UVALDE	1511			
ADAMS AND LYLES	MATHEWS NO. 1	8 MILES FR. N. AND 12 MI. FR. W. COUNTY LINE	ZAVALLA	784	3125	3240	3400
BAY OIL	NAT'L BANK OF COMMERCE NO. 1	35 MILES SOUTHWEST OF PEARSALL	ZAVALLA	700	6480	6592	6721
GRAVES	FARMERS INSURANCE CO. NO. 1	2¼ MILES FR. W. LINE & 3 MI. FR. N. COUNTY LINE	ZAVALLA	874	2515	2640	2800
SOUTHERN CRUDE	WASHER NO. 1	12 MILES SOUTH OF UVALDE	ZAVALLA	753	2155	2309	2465
HUMBLE OIL & REF.	DENTON ESTATE NO. 1	10 MILES FR. N. & 17 MI. FR. E. COUNTY LINE	DIMMIT	517	6585	6720	6845 or 6875
TEXAS AND MARYLAND	MC KNIGHT NO. 1	4½ MI. SW. OF CARRIZO SPRINGS	DIMMIT	684	5757	5915	6155
RYCADE OIL	SULLIVAN NO. 5	13 MIL. FR. N. AND E. LINES OF COUNTY	MAVERICK	863	2217	2367	2607
WELLINGTON OIL	CHITTIM NO. 1-A	24 MI. FR. N. AND 11 MI. FR. E. COUNTY LINE	MAVERICK	775	2678 or 2690	2815	3095
WELLINGTON OIL	CHITTIM NO. 2	26 MILES FR. N. & 9 MI. FR. E. COUNTY LINE	MAVERICK	829	2492	2662	2915
WELLINGTON OIL	CHITTIM NO. 1	ABOUT SAME	MAVERICK	819	2520	2680	2934
RYCADE OIL	CHITTIM NO. 1 UNIT 1	14 MILES FR. N. & 15 MI. FR. W. COUNTY LINE	MAVERICK	789	2438	2590	2870
RYCADE OIL	CHITTIM NO. 2	ABOUT SAME	MAVERICK	745	2459	2617	2896
MAGNOLIA	WARDLAW NO. 1	10¾ MI. EAST OF DEL RIO	KINNEY	998	190	290	430
MEXICAN GULF	SAN AMBROSIO NO. 1	32½ MI. S. 45 W. OF LAREDO IN NUEVO LEON	NUEVO LEON	640	4060	4160	4230
AMERICAN SMELTING AND REFINING	LAS UVAS (PEYOTES) NO. 1	44 MILES S 28° W. OF EAGLE PASS	COAHUILA	1860 GR.	SURFACE	?	90
OHIO MEX	CLOETE NO. 1	58 MILES S. 34° W. OF EAGLE PASS	COAHUILA	1540	SURFACE	90	120
OHIO MEX	TREVINO NO. 1	15½ MI. S. 62° W. OF DEL RIO	COAHUILA	1457			
OHIO MEX	ZAMBRANO NO. 1	33 MILES WEST OF DEL RIO	COAHUILA	1640			SURFACE

TABLE II—*Continued*

KIAMICHI FORMATION	EDWARDS LIMESTONE	GLEN ROSE LIMESTONE	PEARSALL FORMATION: HENSELL MEM.	PEARSALL FORMATION: COW CREEK L.S. MEM.	PEARSALL FORMATION: PINE ISLAND SH. MEM.	SLIGO FORMATION	HOSSTON FORMATION	JURASSIC	PALEOZOIC OR PRE-CAMBRIAN	TOTAL DEPTH
4682	4699	5125	6365?	6390?	6450?	6687?	6895	8900, ESTIMATED		7217
6290	6308									6328
?	6392	6595	8175?	8205?	8250?	8334	8697			8787
ABSENT	1766	FAULTED 2190	2590 or 2650	2610 or 2740	2650 or 2770	2740 or 2800	3280			3360
ABSENT	1210	1630	2090 or 2111	2160?	2210?	2290?	2715	ABSENT	3405	3445
	FAULTED 2760	FAULTED 3270	4095	4125	4180	4265	4915	ABSENT	5440	5509
ABSENT	330 or 343	929?	1745?	1815?	1870?	1975?	2285	ABSENT	2640	3004
ABSENT	465	1011	1930	2208?	2268	2497	2686	ABSENT	2864	3783
ABSENT	1224	1855	2750?	2900?	3025?	3135?	3415			3480
ABSENT	1610	2200	3150?	3360?	3448?	3565?	3925?			4535
ABSENT	2278	2909	3980	4030	?	4180	4882			5361
ABSENT	95	525 or 580	1240	1335	1475	1650	1710	ABSENT	1770	1910
		ON SURFACE	433	487	535	690?	775?	ABSENT	1015	2500
	FAULTED 7485	8700 or 8850								9390
ABSENT	845	1650?					3010			3449
ABSENT	1065 or 1121	1850?					3495			3512
ABSENT	6210	6992 or 7025	8835	9175	9260	9360	10045			10741
ABSENT	5990	6815	8560	8800	8955	9075	9830			10045
2070 or 2315	2480	2800	3570?	3883?	4028?	4600?	4800?			4810
	ON SURFACE	370 or 480	1900	1970?	2160	2340	2580	ABSENT	3460	5015
		ON SURFACE	480?	565?	935?	1120?	1205		1830	2710
3935	4275									4385
6880	7000									7082
3400	3674									3858
2968	3331	3755?								4707
7177 or 7237	7730 or 7820									8013
6615 or 6730	7038									7090
3310	3540	4200					6513?			7494
3785	4075	4725								5891
3630	3848	4550								4877
3600	3816	4510								5688
3575	3810	4520								5735
3600	3830	4530 or 4590					6800?			7635
935 or 980	1185	1510	2540	2605	2705?	2810?	2950		3090	5280
4430?	4550?	5190?				6000		8600		9312
490?	570?	1040?	2675?			3075				4175
490?	540?	1015?	2640?			3060				4185
		367?				2700?	3200			5920
	110?	780?				2230?	2630			4430

FIG. 1.—Index map of southern Texas and northern Mexico s



Mexico showing location of wells listed in Table II.

TABLE III

KNOWN RANGE IN THICKNESS OF CRETACEOUS FORMATION OF PRE-GULF AGE IN SOUTH TEXAS

FORMATION	EDWARDS COUNTY	KINNEY COUNTY	MAVERICK COUNTY	REAL COUNTY	UVALDE COUNTY	ZAVALA COUNTY	DIMMIT COUNTY	MEDINA COUNTY	FRIO COUNTY	BEXAR COUNTY	ATASCOSA COUNTY	COMAL COUNTY	GUADA-LUPE CO.	CALDWELL COUNTY	TRAVIS COUNTY	LEE COUNTY	BURLESON COUNTY	BASTROP COUNTY
BUDA LIMESTONE	5 TO 25	100	135 TO 170	0 TO 8	8 TO 100	110 TO 155	135 TO 160	35 TO 60	120 TO 150	40 TO 80	75 TO 100	50	70	50 TO 75	25 TO 55	60 TO 70	65 TO 80	60
GRAYSON SHALE	10	140	240 TO 280	0 TO 6	6 TO 125	130 TO 160	125 TO 240	8 TO 60	90 TO 95	40 TO 70	65 TO 70	35	40	40 TO 50	40 TO 80	65 TO 70	43 TO 120	120
GEORGETOWN LIMESTONE	150 TO 220	505	565 TO 720	200	30 TO 235	160 TO 600	330 TO 575	40 TO 75	90 TO 110	27 TO 65	35 TO 100	45	40	35 TO 50	45 TO 130	135 TO 200	215 TO 250	210
KIAMICHI FORMATION	absent	200 TO 250	215 TO 290	absent	0 TO 410	120 TO 365	305 TO 550	absent	absent	absent	absent	absent	absent	absent	absent	0 TO 40	0 TO 18?	?
EDWARDS AND COMANCHE PEAK LIMESTONES	325 TO 675	300 TO 325	650 TO 710	400	450 TO 670	425		470 TO 805	780 TO 825	430 TO 650	690	490	510+	420 TO 600	365 TO 480	205	?	550
GLEN ROSE LIMESTONE	450 TO 500	1030	2300?	365 TO 520	1000 TO 1530			785 TO 800	1745 TO 1845	600 TO 1070	690+ TO 1150	740	825+	460 TO 1060	500 TO 700+	1580		1290
PEARSALL FORMATION (TRAVIS PEAK FM. ON OUTCROP): HENSELL SHALE MEMBER		65	112?	70	70 TO 315			80	240 TO 340	50 TO 280		40 TO 45	30	30 TO 70	80 TO 183	30		
PEARSALL FORMATION (TRAVIS PEAK FM. ON OUTCROP): COW CREEK LIMESTONE MEMBER		100	200?	25?	145 TO 370			128?	85 TO 155	55 TO 140		75	55	50	30 TO 100+	45		440
PEARSALL FORMATION (TRAVIS PEAK FM. ON OUTCROP): PINE ISLAND SHALE MEM. OR EQUIVALENT		105	40?	40	180 TO 572?			150	100 TO 120	110 TO 230		65	85	80 TO 90	35 TO 265+	85		
SLIGO FORMATION		140	130?	40	85 TO 240			208	685 TO 755	60 TO 700		?	650	420 TO 540	175?	365		150
HOSSTON FORMATION		140	500+	100	0 TO 880			0 TO 440	695+	60 TO 240		400	525	690		90+		

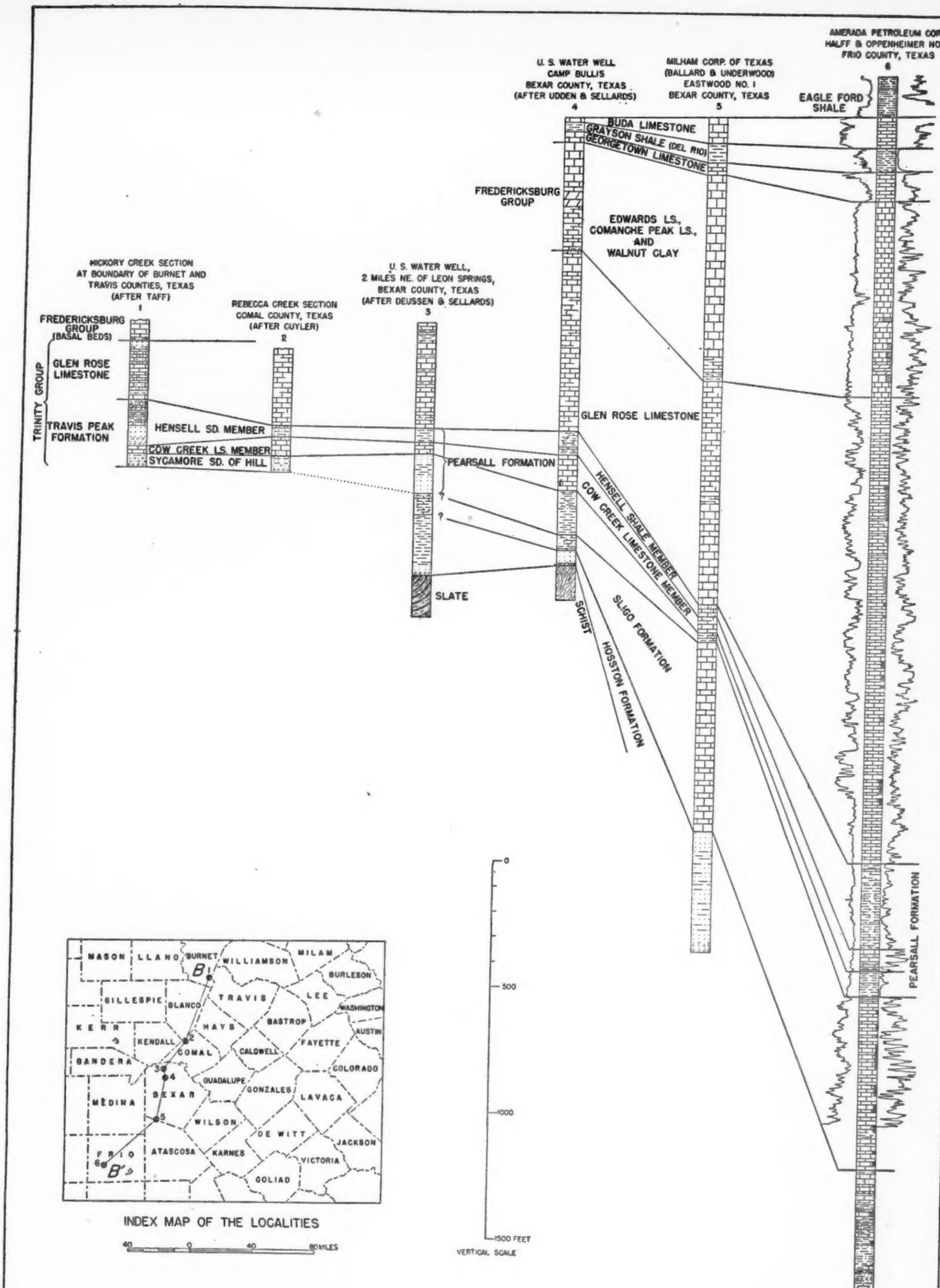


FIG. 2.—Columnar sections from Central Mineral Region to Frio County, Texas.

embayment the contact is transitional and dffiicult to select. Where the Kiamichi formation has been removed by pre-Georgetown erosion, the upper part of the Edwards limestone may be cavernous. The middle Albian age of Edwards limestone is well established.

The Kiamichi formation in South Texas occurs entirely in the subsurface (Figs. 2–5), ranges from 120 to more than 550 feet in thickness (Table III), and consists of hard, dense, calcareous, brownish black to black shale and shaly limestone interbedded with considerable anhydrite and, locally, rock salt. It pinches out not far northward in Valverde, Kinney, and Uvalde counties and is absent over the crest of the San Marcos arch owing to erosion in early Georgetown time. The late middle Albian age of the Kiamichi formation is based on ammonites found in outcrops.

The Georgetown limestone in the subsurface of South Texas ranges in thickness from about 30 to more than 720 feet (Table III), consists mainly of units of soft, chalky white to brown limestone and shale alternating with units of hard, dense, gray to brownish gray limestone, and grades upward into the Grayson shale through 10 to 20 feet of transitional beds (Figs. 2–5). West of Uvalde County it passes into the upper part of a rudistid facies known as the Devils River limestone. The upper Albian age of the Georgetown limestone is shown by the presence throughout of *Pervinquieria*, or closely related genera. The Cenomanian age of the Grayson shale is shown (1) by the occurrence of *Engonoceras* and evolute *Scaphites*, similar to forms in the Cenomanian of Africa, (2) by the absence of distinctly upper Albian ammonites, and (3) by the presence of *Cunningtoniceras*, a Cenomanian genus, in the transitional beds at the base of the Grayson shale. The Cenomanian age of the Buda limestone is shown by the presence of the ammonites *Mantelliceras*, *Sharpeiceras*, and *Euhystrichoceras*. Some paleontologists have supported an upper Albian age for the Grayson shale and the Buda limestone on the basis that the Grayson shale contains *Stoliczkaia* aff. *S. dispar* (D'Orbigny) and that the Buda limestone is the southern Texas equivalent of the upper part of the Grayson shale. However, recent studies have shown definitely that the Buda limestone overlies the Grayson shale normally in the East Texas basin, and that its absence locally is a result of erosion prior to the deposition of the Gulf series. The writer considers that the faunal evidence for the Cenomanian age of the Buda limestone is conclusive, and that the evidence that has been presented for the Cenomanian age of the Grayson shale is stronger than that for its Albian age.

HOSSTON FORMATION

Definition.—The term Hosston formation was chosen by the Shreveport Geological Society[3] for the red and gray shales, dolomites, limestones, and sandstones lying above the Jurassic Cotton Valley group, and below the Sligo formation.

[3] R. W. Imlay, "Lower Cretaceous and Jurassic Formations of Southern Arkansas and Their Oil and Gas Possibilities," *Arkansas Geol. Survey Inform. Cir. 12* (1940a), p. 28.

The Hosston formation was named after the town of Hosston, Louisiana, and the Dixie Oil Company's Robertshaw No. 92 (Dillon No. 92), in Sec. 13, T. 21 N., R. 15 W., was designated the type well. The formation is entirely subsurface in the coastal plain, occupies the same stratigraphic position throughout, and must be of Neocomian age except in marginal areas where it rises stratigraphically at the expense of the overlying Sligo formation.[4]

The Hosston formation is still commonly called Travis Peak formation by well drillers and many geologists, but available evidence (Table I and Fig. 2) shows that the Hosston formation of South Texas was not deposited much farther inland than the Balcones fault zone, and that the sea of Hosston time was receiving sediments from the area where the typical Travis Peak formation was subsequently deposited. The writer recommends that the term Travis Peak formation be used hereafter only for outcrops.

Distribution and thickness.—The Hosston formation has been identified in South Texas in about a dozen wells located in Maverick, Uvalde, Frio, Bexar, Guadalupe, and Lee counties. In most of these wells the complete thickness of the formation is not known, as only a slight thickness was penetrated. In the Humble Oil and Refining Company's R. L. Anderson No. 1, southern Uvalde County, the Hosston formation rests on Paleozoic rocks and is about 910 feet thick. In the Diamond-Half Oil Company's Bibbs No. 1, Guadalupe County, the formation apparently rests on schist and is 520 feet thick. In the Amerada Petroleum Corporation's Halff and Oppenheimer No. 8, Frio County, the incomplete thickness of the formation is about 696 feet. The thickness of the Hosston formation, where underlain by Jurassic rocks, is estimated to be between 1,100 to 2,000 feet, judged by known thicknesses of equivalent beds in eastern Texas, northern Louisiana, and northern Mexico. A somewhat greater thickness is suggested by the considerable thickening from East to South Texas of all the formations between the Kiamichi and the Hosston. This agrees with Getzendaner's[5] postulation that the thicknesses of the Hosston and of the Jurassic formations in South Texas are greater than in East Texas, Louisiana, and Arkansas "at comparable locations with reference to the shore." However, he presents evidence[6] that the combined thickness of these formations in the Chittim field of Maverick County is about the same as "at comparable locations with reference to the margin of the basin in Arkansas."

Stratigraphic and lithologic features.—The known complete sections of the Hosston formation in South Texas are underlain directly by Paleozoic, or older rocks, and appear to represent marginal deposits formed during the latter part of Hosston time. The characteristics of the entire formation will not be known until

[4] B. W. Blanpied and R. T. Hazzard, "Interesting Wildcat Wells Drilled in North Louisiana in 1942," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28 (1944), pp. 327, 328.

[5] F. M. Getzendaner, "Problem of Pre-Trinity Deposits in South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 9 (1943), pp. 1228, 1240.

[6] *Ibid.*, p. 1243.

it is penetrated in areas underlain by Jurassic rocks. The part of the formation that has been penetrated consists at the top of dark, calcareous beds, in the middle of dominantly red sandstone and shale, and at the base of varicolored conglomerate in a matrix of dominantly red sandstone and shale. The calcareous beds at the top range from 300 to 500 feet in thickness; consist mainly of gray to brown limestone interbedded with much green, gray to black lignitic shale, and gray to white sandstone; and grade upward within a few feet into the dolomitic limestone of the Sligo formation. It seems probable that they grade offshore into the lower part of the Sligo formation, in the same manner as the upper part of the Hosston formation of the Arkansas-Louisiana area.[7] Underlying the calcareous beds are several hundred feet, or more, of reddish sandstone, sandy shale, and shale containing minor amounts of gray limestone. Some of the sandstone is gray or white, and some of the shale is green, gray, or black. Core specimens indicate that cross-bedding is common. These beds grade downward into conglomeratic sandstone and shale at the base of the formation.

The Hosston formation of South Texas differs from the same formation in the Arkansas-Louisiana-East Texas area by a nearly complete lack of red beds in its upper few hundred feet and by containing much more calcareous material. These features, plus the consideration that the Central Mineral region appears to have been a smaller, less important source of sandy sediments than the Ouachita region, suggest that offshore beds of the Hosston formation in South Texas will be found to contain many beds of calcareous shale and limstone.

The best known sections of the Hosston formation in South Texas may be summarized as follows.

HOSSTON FORMATION IN AMERADA PETROLEUM CORPORATION'S HALFF AND OPPENHEIMER NO. 8, ABOUT 10 MILES SOUTHWEST OF PEARSALL, FRIO COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Limestone, gray, partly sandy; some very fine-grained, white sandstone	10,045–10,052	7
Sandstone, fine-grained, white, interbedded with gray sandy limestone and black shale	–10,060	8
Limestone, gray, hard, dense; interbedded with considerable black shale and a little white, fine-grained sandstone	–10,075	15
Limestone, gray to tan, hard, dense, interbedded with small amounts of black shale and gray to white, fine-grained sandstone	–10,105	30
Limestone as above, with considerable white, fine-grained sandstone and a little black shale	–10,115	10
Limestone, gray, tan, and brown, hard, dense to coarsely crystalline; minor amounts of chalky limestone and black shale	–10,130	15
Limestone, gray to tan, hard to medium soft, dense to finely crystalline; considerable gray to white, fine-grained sandstone; some black shale.	–10,140	10
Limestone, gray to tan, hard, dense, partly sandy; considerable black shale; small amounts of green and red sandy shale, and gray, white, and red, fine-grained sandstone; fragments of oysters	–10,165	25
Limestone, gray to brown, hard, dense to finely crystalline, interbedded with considerable red and black shale and red and white sandstone that become more abundant toward the base	–10,200	35
Sandstone, white and red, very fine-grained; considerable gray to tan hard limestone and black to red shale	–10,205	5

[7] Ralph W. Imlay, *op. cit.* (1940a), p. 29.

	Depth in Feet	*Thickness in Feet*
Limestone, gray to tan, mostly hard and dense, some soft and sugary; small amounts of black, gray, and red shale and of white and red sandstone, traces of selenite gypsum	−10,230	25
Limestone as above, considerable gray to black shale, small amounts of red shale and of white to red sandstone	−10,255	25
Sandstone, red and white, hard, very fine-grained; considerable gray to black shale and gray to brown, dense limestone; traces of green and red shale	−10,260	5
Limestone, gray to tan, hard, dense to finely crystalline, interbedded with with considerable gray, black, green, and red shale, and red and white sandstone; some dolomitic limestone	−10,290	30
Shale, partly sandy, gray, black, red and green; considerable gray, green, tan to brown, dense limestone, and white to red, fine-grained sandstone	−10,310	20
Shale, gray, black, green, red, becomes redder toward base; considerable limestone as above; small amounts of white and red sandstone; trace of anhydrite near base	−10,341	31
Sandstone, white, medium-grained; a little shale and limestone	−10,350	9
Shale, black, and considerable white sandstone	−10,360	10
Sandstone and shale, mainly red, some black shale	−10,380	20
Shale and considerable sandstone, mainly red; some black shale	−10,400	20
Shale, sandy, red mainly; a little white, fine-grained sandstone	−10,425	25
Limestone, mostly sandy, light gray, and an equal amount of shale that is dominantly red	−10,440	15
Shale, sandy, red mainly, some black	−10,445	5
Shale, sandy shale, and sandstone, micaceous, mainly red, a few quartz pebbles near base	−10,480	35
Shale, sandy, red, coarse-grained, red and white sandstone, and considerable gray, white, and pink limestone	−10,510	30
Shale, red, predominant; some pink to white sandstone and limestone. .	−10,530	20
Shale, red and gray, and much pink to white, coarse-grained sandstone.	−10,550	20
Shale, red and gray, and an equal amount of white, medium- to coarse-grained sandstone	−10,575	25
Shale, red and brown, micaceous; a little pink and white, medium- to coarse-grained sandstone	−10,585	10
Shale, red, and an equal amount of white, medium- to coarse-grained sandstone	−10,600	15
Shale, red and gray, micaceous, and considerable pink to white, medium- to coarse-grained sandstone that becomes more abundant toward base	−10,650	50
Shale, red, and much pink, coarse-grained sandstone	−10,660	10
Shale, red, micaceous, and an equal amount of pink to white, medium- to coarse-grained sandstone	−10,695	35
Shale, red and gray, micaceous; about one-third red and white, medium-grained sandstone; a few fragments of quartzite and schist; trace of gray limestone	−10,710	15
Shale and sandstone as above and much coarse-grained, varicolored sandstone	−10,720	10
Sandstone, fine-grained, pink and white, and considerable red sandy shale.	−10,730	10
Sandstone, medium-grained, gray to white, and an equal amount of red sandy shale	−10,735	5
Shale, partly sandy, red and black, interbedded with gray to white medium-grained sandstone; some coal fragments	−10,741½	6½
Total thickness		696½

The foregoing section may be summarized as follows.

	Depth in Feet	*Thickness in Feet*
Limestone predominant, gray to tan, hard, mostly dense, interbedded with some black shale and white, fine-grained sandstone	10,045–10,130	85
Limestone interbedded with much shale and some sandstone. Limestone		

	Depth in Feet	Thickness in Feet
is gray to brown, mostly hard and dense. Shale is black to red, or rarely green. Sandstone is white and red, and very fine-grained. A few oyster fragments present	−10,340	210
Sandstone, sandy shale, and shale, and minor amounts of limestone. Sandstone fine- to medium-grained, mainly red, some white; conglomeratic near base. Shale mainly red, some black, rarely green	−10,480	140
Shale interbedded with some limestone and coarse-grained sandstone, varicolored	−10,530	50
Shale, mainly red, interbedded with much pink to white, medium- to coarse-grained sandstone that includes fragments of quartzite and schist and basally some coal fragments	−10,741½	211½
Total thickness		696½

HOSSTON FORMATION IN DIAMOND-HALF OIL CORPORATION'S BIBBS NO. 1, EASTERN GUADALUPE COUNTY, TEXAS

	Depth in Feet	Thickness in Feet
Shale, green and gray, interbedded with considerable white, fine-grained sandstone and gray, porous dolomitic limestone or dense limestone	4,920–5,050	130
Limestone, dense, light gray, interbedded with much light green, gray, and black splintery shale, and a little gray to white, fine-grained sandstone	−5,165	115
Shale and considerable limestone as above	−5,260	95
Limestone, light gray, interbedded with considerable green and gray shale, some gray and white sandstone, and a little gypsum; some pink limestone and sandy shale below 5,280	−5,305	45
Shale, sandy shale, and sandstone, mainly red; some green and gray shale; a little gray limestone; many quartzite and schist pebbles	−5440	135
Total thickness		520

The foregoing section rests on schistose rocks, or perhaps on a conglomerate consisting of gray sericitic schist, black graphitic schist, red micaceous schist, green chloritic schist, quartz, calcite, and pyrite. The characteristics of the electric log suggest that the rock is more probably a schist. The contact of the Hosston formation with the overlying Sligo formation appears to be gradational within a few feet.

HOSSTON FORMATION IN HUMBLE OIL AND REFINING COMPANY'S R. L. ANDERSON NO. 1, UVALDE COUNTY, TEXAS

	Depth in Feet	Thickness in Feet
Sandstone, medium- to fine-grained, light gray to tannish gray, alternating with much gray to green shale and sandy shale and some gray sandy limestone; includes some lignite	2,550–2,700	150
Sandstone, fine- to coarse-grained, light gray to white, alternating with some gray to green shale and sandy shale; traces of lignite	−3,150	450
Conglomerate, varicolored, alternating with gray, medium- to coarse-grained sandstone, and gray to green shale and sandy shale. Some pink shales in lower 100 feet	−3,460	310
Total thickness		910

The foregoing section rests on hard, jointed, black shale, sandy shale, and gray to black quartzite that shows dips of 40° to 90° and is generally considered to be

Pennsylvanian in age. It passes gradationally upward into sandy limestone in the lower part of the Sligo formation.

For comparative purposes one of the best known sections of the Hosston formation in the southern part of East Texas basin is described as follows.

HOSSTON FORMATION IN STANOLIND OIL AND GAS COMPANY'S TENNIE NORRIS NO. 1, TWO MILES WEST OF THORNTON, LIMESTONE COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Sandstone, hard, gray, fine-grained to silty, slightly calcareous; some shale laminae	5,525-5,540	15
Shale, mostly sandy, interbedded with silty to very fine grained sandstone, mainly light to dark gray, some pink, calcareous, hard; a few streaks of lignite	-5,588	48
Sandstone, hard, mostly gray, some red, partly laminated; some layers of sandy shale	-5,605	17
Shale, sandy, laminated, gray to greenish gray, interbedded with some gray to red, silty sandstone	-5,680	75
Sandstone, fine-grained, micaceous, gray, yellow, pinkish, slightly calcareous	-5,730	50
Shale, gray, and very fine-grained, white to gray micaceous sandstone	-5,780	50
Sandstone, fine-grained, micaceous, slightly calcareous	-5,790	10
Shale, hard, gray, brittle, slightly calcareous	-5,800	10
Shale, sandy, and sandstone, fine- to medium-grained, white	-5,830	30
Sandstone, mostly fine-grained, hard, white to light gray; some pinkish beds near base	-5,895	65
Shale, splintery, gray-green, slightly calcareous	-5,915	20
Sandstone, fine- to medium-grained, gray, white, and pink; a few layers of white, dense limestone; some reddish brown shale	-6,050	135
Sandstone, fine-grained, white to gray; some gray shale	-6,150	100
Sandstone, hard, medium- to coarse-grained to pebbly, white, gray, pinkish; some layers of gray, green, and chocolate red shale	-6,350	200
Sandstone, medium- to coarse-grained, white, interbedded with greenish gray and red shale and some gray limestone	-6,400	50
Sandstone, fine- to coarse-grained to pebbly, white; some gray to green shale	-6,500	100
Sandstone, medium- to fine-grained, gray to red, interbedded with considerable gray, green to maroon shale	-6,580	80
Shale and sandstone interbedded. Shale, gray, green, maroon, locally mottled, some layers micaceous. Sandstone, fine- to medium-grained white to red, some gray dolomitic limestone	-6,730	150
Sandstone, fine- to coarse-grained, white; some interbedded gray to green shale, slightly calcareous	-6,840	110
Sandstone, fine- to medium-grained, white; some greenish shale	-6,895	55
Sandstone, medium- to coarse-grained; contains pebbles of varicolored chert and quartz; some maroon and green shale	-6,970	75
Sandstone, fine- to medium-grained, interbedded with considerable red and green shale and sandy shale; some gray, dolomitic limestone near base	-7,055	85
Sandstone, coarse-grained, white; varicolored chert pebbles abundant	-7,095	40
Total thickness		1,570

The 1,800 feet of the Hosston formation penetrated in the Ohio-Mexican Oil Company's Zambrano well No. 1 in northern Coahuila is of considerable interest for comparisons with sections in Texas and for indicating the position of the Neocomian landmass. The following section is abstracted from a report made by Robert H. Cuyler for The Ohio Oil Company and has not been published previously.

HOSSTON FORMATION IN OHIO-MEXICAN OIL COMPANY'S ZAMBRANO NO. 1, ABOUT 33 MILES WEST OF DEL RIO, TEXAS, IN NORTHERN COAHUILA

	Depth in Feet	*Thickness in Feet*
Sandstone, calcareous, consisting mainly of angular, white quartz grains.	2,630–2,710	80
Sandstone as above and some limestone	–2,760	50
Sandstone, fine-grained, white	–2,810	50
Limestone, gray; some pyrite	–2,820	10
Sandstone, white; some black shale	–2,870	50
Sandstone, white to gray, calcareous to siliceous	–2,910	40
Sandstone, mostly fine-grained, white; some black shale and soft pink limestone	–2,930	20
Sandstone, fine-grained, white, calcareous; considerable gray to black limestone	–2,980	50
Sandstone, coarse- to fine-grained, white to dark gray, calcareous to siliceous	–3,030	50
Sandstone, fine-grained, white, calcareous; considerable gray shale	–3,060	30
Sandstone, fine-grained, white	–3,110	50
Sandstone, coarse-grained; much shale	–3,200	90
Sandstone, mostly coarse-grained, siliceous to calcareous; some black shale	–3,230	30
Sandstone, coarse-grained, white, and black shale and limestone	–3,240	10
Sandstone, fine-grained, reddish	–3,250	10
Sandstone, dolomitic, grains consist of quartz and magnetite; contains rounded pebbles of fine-grained, yellowish sandstone, of soft sandy shale, and black chert	–3,270	20
Sandstone, fairly coarse-grained, reddish, composed mainly of quartz grains, contains rounded pebbles of reddish sandstone, black, argillaceous sandstone, black chert and quartz	–3,420	150
Sandstone, coarse-grained, composed mainly of quartz grains; contains some pebbles of white sandstone	–4,050	630
Sandstone, very coarse-grained, composed of grains of quartz and quartzite; contains large pebbles of white sandstone and red sandstone; some selenite present	–4,165	115
Conglomerate of quartz pebbles in a matrix of mica, quartz, and quartzitic material; one fragment of mica schist noted	–4,196	31
Arkose consisting mainly of quartz, pink feldspar, and dark to light-colored mica	–4,209	13
Conglomerate consisting mainly of small pebbles of quartz, but including a few large pebbles of red sandstone, mica schist, and quartz schist; many quartz grains and mica flakes present	–4,230	21
No record	–4,350	120
Sandstone consisting of grains of quartz, quartzite, and schistose material; contains some well rounded quartz pebbles	–4,375	25
Conglomerate, composed entirely of medium-sized rounded quartz pebbles and larger angular fragments of quartz and schist	–4,420	45
Schist fragments	–4,430	10
Total thickness		1,800

The foregoing section contains three distinct subdivisions. Its upper 610 feet consists of fine- to coarse-grained, white to gray quartz sandstone that includes some beds of gray to black shale and gray limestone. Below follows about 180 feet of reddish sandstone containing some pebbles of black chert and of red and black sandstone. Below follows 745 feet of coarse-grained, white, quartz sandstone containing some large pebbles of white sandstone. The lower 265 feet penetrated is a conglomerate consisting of pebbles of quartz, quartzite, and schist.

The Ohio-Mexican Oil Company's Treviño well No. 1, about 15½ miles southwest of Del Rio, is reported to have penetrated red sandstone and arkose from depths of 3,200 to 5,920 feet, but detailed records are not available.

Correlation.—The Hosston formation of the subsurface of South Texas occupies the same stratigraphic position as the Hosston formation of the Arkansas-Louisiana-East Texas area and similarly must be mainly of Neocomian age, except in marginal areas where the Sligo formation changes into a sandy facies that, on a lithologic basis, is generally included in the Hosston formation. As fossils have not been found in the Hosston formation its age determination is based on its stratigraphic position above definite late Jurassic beds and below the Sligo formation, which is mainly lower Aptian in age.

In northern Mexico the equivalents of the Hosston formation consist of near-shore sandy to conglomeratic facies, and offshore shaly to calcareous facies. In contrast to conditions in the Gulf region of the United States, where drilling has penetrated only a sandy to conglomeratic facies of Neocomian age, the many mountainous uplifts of Nuevo León, Coahuila, and Chihuahua exhibit both near-shore and offshore facies and interfingering of the various facies. The distribution of the sandy to conglomeratic facies is in a belt from 50 to 75 miles wide bordering the site of the Coahuila Peninsula of Neocomian time. Deposits comparable in coarseness and thickness with the Hosston formation crop out in the Southern Quitman Mountains of Hudspeth County, Texas,[8] in the Cuchillo Parado area of northeastern Chihuahua,[9] in the mountains west of the Laguna district in eastern Durango,[10] at Barril Viejo and Valle de Muralla in east-central Coahuila,[11] and have been penetrated by drilling in the Ohio-Mexican Oil Company's Zambrano well No. 1 and Treviño well No. 1 in north-central Coahuila. It seems unlikely that any of the coarse sediments encountered in these wells are of Jurassic age, contrary to the opinion of Getzendaner,[12] although Jurassic rocks may underlie the area in which the wells were drilled. Desposits representing interfingering of sandy and calcareous facies crop out in the Sierra de Jimulco and in the western part of the Sierra de Parras in southern Coahuila[13] and in the Potrero de Men-

[8] J. A. Taff, "The Cretaceous Deposits [of El Paso County]," *Texas Geol. Survey Ann. Rept. 2* (1891), pp. 730, 731.
W. S. Adkins, "The Mesozoic Systems in Texas" in "The Geology of Texas, Vol. 1, Stratigraphy," *Univ. Texas Bull. 3232*, Pt. 2 (1933), pp. 291, 292.
Gayle Scott, "Cephalopods from the Cretaceous Trinity Group of the South Central United States," *Univ. Texas Pub. 3945* (1940a), Pl. 55.

[9] R. H. Burrows, "Geology of Northern Mexico," *Bol. Soc. Geol. Mexicana*, T. 7 (1910), pp. 85–103.

[10] L. B. Kellum, "Geology of the Mountains West of the Laguna District," *Bull. Geol. Soc. America*, Vol. 47 (1936), pp. 1053–1070.
R. W. Imlay, "Neocomian Faunas of Northern Mexico," *Bull. Geol. Soc. America*, Vol. 51 (1940b), p. 124.

[11] Carlos Burckhardt, "Étude synthétique sur le mésozoique méxicain," *Soc. Paléon. Suisse Mém.*, Vols. 49, 50 (1930), pp. 146.
R. W. Imlay, *op. cit.* (1940b), p. 121.

[12] F. M. Getzendaner, "Problem of Pre-Trinity Deposits in South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27 (1943), p. 1233.

[13] R. W. Imlay, "Studies of the Mexican Geosyncline," *Bull. Geol. Soc. America*, Vol. 49 (1938), p. 1688, Fig. 4.
———, "Geology of the Western Part of the Sierra de Parras," *ibid.*, Vol. 47 (1936), pp. 1111–19, Pl. 7.

chaca of east-central Coahuila.[14] Offshore calcareous shale and limestone equivalent to the Hosston formation are widespread in central and eastern Mexico and were pentrated in the Rio Grande embayment by the Gulf Oil Company's San Ambrosio well No. 1, about 52 kilometers S. 45° W. of Laredo, Texas.[15] The nearest outcrops of this facies to the Texas area are in the Potrero de Oballos of east-central Coahuila.[16] These occurrences demonstrate an offshore gradation from coarse, clastic sediments to fine, calcareous sediments and suggest that a similar gradational relationship may be encountered in South Texas. Thus, the records of the cuttings obtained from the lower 800 feet penetrated in the Rycade Oil Corporation's Sullivan well No. 5, Maverick County, Texas, indicate the presence of much more shale than has been found in the Hosston formation elsewhere in Texas.

SLIGO FORMATION

Definition.—The term Sligo formation was proposed by the Shreveport Geological Society and formally defined by Imlay[17] in 1940 for 100 to 300 feet of gray to brown shale containing local lenses of sandstone and limestone and representing the lowest beds of the so-called "lower Glen Rose." Its base was defined by the uppermost red beds of the Hosston formation, and its top by the highest of three limestone units informally called the Three Finger limestone. The Sligo field of northwestern Louisiana was designated as the type locality. The Shreveport Geological Society recognized the term Pettet limestone (generally misspelled Pettit) as an informal name for local, porous, limestone lentils within the Sligo formation. Pettet limestone was not considered acceptable as a formation name, because it was commonly used in Arkansas and Louisiana for a zone, or zones of porosity, as were the approximately equivalent Dixie and Dillon zones of the Pine Island field and the Patton zone of the Lisbon field. Geologists in the East Texas area have expressed the opinion that the term Sligo formation should be abandoned in favor of Pettet formation in order to conform with common usage in that area. It appears to be the more general opinion, however, that the term Sligo should be retained as a formal name, because substitution of the term Pettet for Sligo would result in much confusion. This does not bar the use of the term Pettet as an informal name for a pay zone within the Sligo formation.

Distribution and thickness.—The Sligo formation has been identified in South Texas in Uvalde, Frio, Bexar, Guadalupe, and Lee counties, and it probably is as

———, "Cretaceous Formations of Central America and Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28 (1944), p. 1161.

[14] R. W. Imlay, *op. cit.* (1940b), pp. 121, 122.

[15] R. W. Imlay, "Jurassic Formations of Gulf Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27 (1943), p. 1467.
———, *op. cit.* (1944), p. 1177, Fig. 12.

[16] R. W. Imlay, *op. cit.* (1940b), pp. 122, 123.
———, *op. cit.* (1944), p. 1112.

[17] R. W. Imlay, "Lower Cretaceous and Jurassic Formations of Southern Arkansas and Their Oil and Gas Possibilities," *Arkansas Geol. Survey Inf. Cir. 12* (1940a), pp. 30–32.

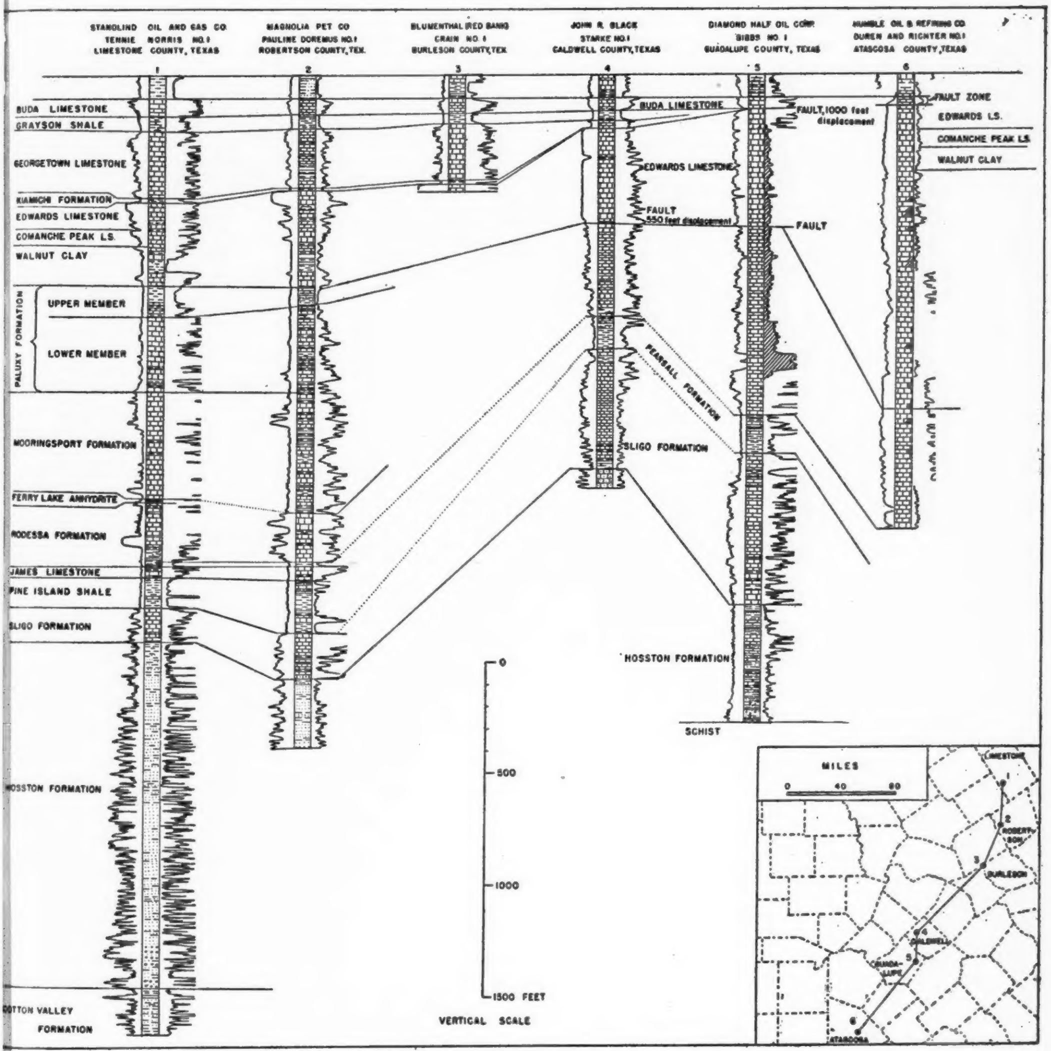


FIG. 3.—Columnar section from Limestone County to Atascosa County, Texas.

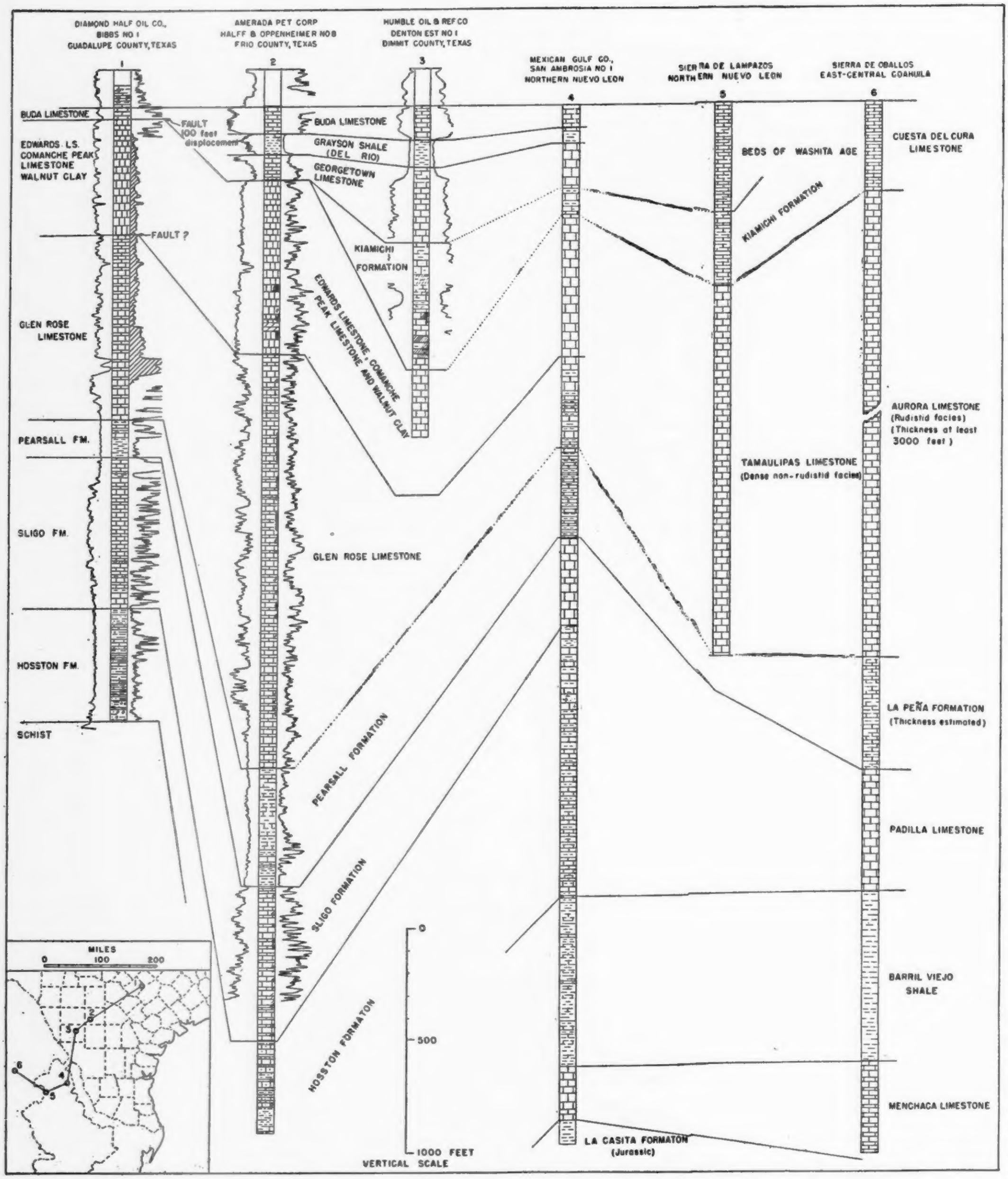


FIG. 4.—Columnar sections from Guadalupe County, Texas, to Sierra de Oballos in east-central Coahuila, Mexico.

extensive as the Hosston formation. Its thickness, as determined in six wells, ranges from 210 to 750 feet. The strike sections (Figs. 3 and 4) from Limestone County to Frio County indicate that the formation thickens southward and is considerably thicker in South Texas than in East Texas.

Stratigraphic and lithologic features.—The Sligo formation of South Texas consists mainly of gray, yellowish gray, and brown limestone separated by many partings and thin units of black shale that amount to perhaps 20 per cent of the entire formation. Its lower three-fourths contain some dolomitic beds and many nodules and thin layers of white anhydrite. Most of the limestone is hard and dense to finely granular, but some is moderately soft and sugary, and a little is chalky. Some oolitic limestone occurs in the upper fourth of the formation. The lower 40 to 50 feet of the Sligo formation contains some sandy limestone and a few thin beds of sandstone, indicating a transitional relationship with the Hosston formation, but the contact between these formations is easily selected within a few feet. The contact with the overlying shale and sandstone at the base of the Pearsall formation is very abrupt, suggesting a sudden change in conditions of sedimentation at the end of Sligo time.

The Sligo formation of South Texas differs from the Sligo formation of the Arkansas-Louisiana-East Texas area by being somewhat thicker, more calcareous, less sandy, denser, and by containing considerable anhydrite and some dolomitic limestone. It greatly resembles the lower part of the Cuchillo formation of western Coahuila and eastern Chihuahua, and undoubtedly was deposited at the same time.

The best known sections of the Sligo formation in South Texas may be summarized as follows.

SLIGO FORMATION IN AMERADA PETROLEUM CORPORATION'S HALFF AND OPPENHEIMER NO. 8, ABOUT 10 MILES SOUTHWEST OF PEARSALL, FRIO COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Limestone, dense to finely crystalline, fossiliferous, hard, gray to tan to brown; and nearly as much calcareous, brittle black shale; some pyrite.	9,360–9,375	15
Limestone as above and minor amounts of black shale	–9,410	35
Limestone and shale as above, but including some tan to brown, fine sugary-textured, medium-soft limestone	–9,425	15
Limestone, dense to finely crystalline or, uncommonly, sugary, gray to tan to brown; traces of chalky limestone and anhydrite; about 25 to 30 per cent black shale; some beds contain miliolids	–9,518	93
Shale, black, and some limestone as above	–9,525	7
Limestone, mostly medium-soft, finely sugary, tan, with dark spots; some hard, dense, dark brown to gray limestone and black shale; traces of anhydrite	–9,545	20
Limestone, shale, and anhydrite as above, but the hard, dense gray to brown limestone predominates	–9,580	35
Limestone, mostly dense, hard, dark gray to brown, but some is medium-soft, finely sugary and tan; includes about 25 per cent black shale and as much as 15 per cent white anhydrite	–9,615	35
Limestone, mostly hard, dense, dark gray, some tan to brown; very little black shale; trace of anhydrite in some beds	–9,655	40
Limestone as above, plus trace of tan, fossiliferous limestone; becomes browner downward; anhydrite absent	–9,690	35

	Depth in Feet	Thickness in Feet
Limestone, mostly hard, dense, dark gray; traces of tan, sugary limestone, gray fossiliferous limestone, and brown dolomite crystals; from 25 to 30 per cent black shale	-9,725	35
Limestone, hard, dense, dark gray to tan, predominates; about 25 per cent black shale and from 3 to 25 per cent white anhydrite	-9,740	15
Limestone, lighter in color and more crystalline than above; about 25 per cent black shale; trace of anhydrite	-9,785	45
Limestone, mostly hard, dense to finely crystalline, dark gray; some coarsely crystalline, soft, gray to grown limestone, and some hard, dense, brown limestone; about 20 per cent black shale and from 5 to 10 per cent white anhydrite	-9,830	45
Limestone and shale as above, plus as much as 40 per cent of gray, fossiliferous limestone; anhydrite absent	-9,845	15
Limestone, mostly hard, dense to finely crystalline, dark gray, some tan to brown; trace of gray, soft, chalky limestone; about 25 to 35 per cent black shale; trace of anhydrite in some beds	-9,900	55
Limestone, mostly hard, dense to finely crystalline, gray, tan, brown; some contains dark spots; trace of light gray, fossiliferous chalky limestone; black shale decreases from about 25 per cent at top to 5 per cent, or less, at base	-9,945	45
Limestone, mostly hard, dense, dark gray; very little shale; some fine grains of quartz at top	-9,960	15
Limestone, partly hard, dense, dark gray, partly soft to hard, finely sugary, tan to brown with dark spots; small amounts of black shale and white anhydrite	-9,980	20
Limestone as above but partly sandy and including some dark gray, very fine-grained sandstone	-9,995	15
Limestone, hard, dense to finely crystalline, gray, tan, and brown, with dark gray spots, some soft and fossiliferous; some black shale	-10,010	15
Limestone, mostly hard, dense, gray to tan, some dark gray to black; traces of anhydrite; a few quartz grains near top; becomes slightly shalier near base	-10,045	35
Total thickness		685

Sligo Formation in Humble Oil and Refining Company's R. L. Anderson No. 1, Uvalde County, Texas

	Depth in Feet	Thickness in Feet
Limestone, oölitic to dense gray and tan, and partings of gray shale. Contains *Orbitolina texana* (Roemer), Miliolidae, ostracodes, and oysters	2,340-2,480	140
Limestone, granular to slightly oölitic, tan to gray; partings of gray shale, and nodules of anhydrite	-2,500	20
Limestone, shale, and anhydrite as above, but including some light gray, fine-grained sandstone; contains *Orbitolina texana* (Roemer)	-2,530	30
Limestone, granular to dense or slightly oölitic, tan to gray, in part sandy; includes some gray shale and anhydrite	-2,550	20
Total thickness		210

Sligo Formation in Diamond Half Oil Corporation's Bibbs No. 1, Eastern Guadalupe County, Texas

	Depth in Feet	Thickness in Feet
Limestone, nodular, gray to white, and much dark gray shale	4,265-4,470	205
Limestone, partly dolomitic, gray to yellow-gray; contains small black nodules and some patches of coarsely crystalline calcite; some shaly partings	-4,710	240
Limestone, partly dolomitic, nodular, gray to yellow-gray; much gray shale; trace of anhydrite at top	-4,920	210
Total thickness		655

The following description of the Sligo formation in the southern part of the East Texas basin is based on cores and is interesting for comparison with the sections in South Texas.

SLIGO FORMATION IN STANOLIND OIL COMPANY'S TENNIE NORRIS NO. 1, 2 MILES WEST OF THORNTON, LIMESTONE COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Limestone, hard, gray, pyritic, slightly porous, partly fossiliferous; some shale layers	5,380–5,395	15
Limestone, hard, gray to light brown, oölitic, slightly to fairly porous	–5,404	9
Limestone, hard, gray to brown, fossiliferous, coarsely crystalline	–5,410	6
Limestone, hard, gray, slightly to highly oölitic, tight to medium-porous	–5,428	18
Limestone, hard, gray to light tan, pseudo-oölitic, slightly pyritic; some shale layers	–5,442	14
Limestone, soft, tan to brown, porous, fossiliferous, slightly pyritic	–5,444	2
Limestone, hard, gray, pseudo-oölitic	–5,449	5
Limestone, hard, dark gray to brown, pseudo-oölitic, alternating with thin layers of calcareous gray shale	–5,460	11
Limestone, hard, dense to granular, dark gray, pseudo-oölitic; some gray shale laminae	–5,480	20
Limestone, hard, gray, dense to granular, pseudo-oölitic; some shale	–5,485½	5½
Shale and siltstone, dark gray	–5,488	2½
Limestone, hard, gray, dense to visibly crystalline, pseudo-oölitic; a 6-inch layer of shale 2 feet from top	–5,495	7
Limestone, hard, tan-gray, fossiliferous, oölitic; several shale laminae	–5,498	3
Limestone, hard, medium to dark gray, pseudo-oölitic, dense to granular; some layers silty and laminated	–5,519	21
Limestone, hard, gray to tan, dense to granular, pseudo-oölitic, fossiliferous	–5,523½	4½
Sandstone, hard, gray, fine-grained, shaly, slightly calcareous; a 6-inch layer of pseudo-oölitic limestone at base	5,525	1½
Total thickness		145

In northern Coahuila, Mexico, the equivalents of the Sligo formation encountered in the subsurface show resemblances to both the Texas section and to outcrops in east-central Coahuila and eastern Chihuahua. The best known sections follow.

OHIO-MEXICAN OIL COMPANY'S CLOETE NO. 1, 58 MILES S. 34° W. OF EAGLE PASS, TEXAS, IN NORTHERN COAHUILA

	Depth in Feet	*Thickness in Feet*
Limestone, brown, finely crystalline; small amounts of anhydrite	3,060–3,080	20
Limestone, brown, slightly oölitic; small amounts of anhydrite	–3,110	30
Limestone, brown, finely crystalline	–3,160	50
Limestone, brown, finely crystalline to slightly oölitic; small amounts of anhydrite	–3,180	20
Limestone, brown, oölitic to granular	–3,210	30
Limestone, brown, dense; a little black shale	–3,270	60
Limestone, brown, dense; a little anhydrite	–3,340	70
Anhydrite and brown, granular limestone	–3,350	10
Limestone, brown, granular to finely crystalline; small amounts of anhydrite and black shale	–3,410	60
Limestone, brown, granular, slightly oölitic; traces of black shale	–3,430	20
Limestone, brown, granular to finely crystalline; some anhydrite and black shale	–3,500	70
No sample record. Driller's log indicates gray limestone	–3,600	100
Limestone, brownish gray, dense, some granular and oölitic; some tan-gray limestone near base	–3,800	200
Limestone, tan-gray and granular to brownish gray and dense; some oölitic; some anhydrite and black shale	–3,840	40

	Depth in Feet	Thickness in Feet
Limestone as above but without anhydrite	−4,090	250
Limestone, mostly brownish gray and dense, some tan-gray and finely granular; some anhydrite and black shale; base of formation not penetrated.	−4,185	95
Total thickness		1,125

The foregoing incomplete section differs from the known sections of the Sligo formation of South Texas by being somewhat thicker and by lacking sandy beds at the top.

OHIO-MEXICAN OIL COMPANY'S ZAMBRANO WELL NO. 1, 33 MILES WEST OF DEL RIO, TEXAS, IN NORTHERN COAHUILA

	Depth in Feet	Thickness in Feet
Limestone, dark to light gray, medium hard	2,230–2,340	110
Limestone as above, interbedded with much very fine-grained quartz sandstone	−2,410	70
Limestone, finely to coarsely crystalline, dark gray to white, pyritic, fossiliferous; minor amounts of sandstone	−2,520	110
Limestone, hard, dark gray to almost blue	−2,560	40
Sandstone composed of angular quartz grains	−2,600	40
Limestone, dark gray; very little quartz sandstone	−2,630	30
Total thickness		400

The section of the Sligo formation in the Ohio-Mexican Oil Company's Treviño No. 1 is apparently 500 feet thick and consists of coffee-colored and red sandstone and shaly sandstone interbedded with considerable dark limestone.

Correlation.—A lower Aptian age for the Sligo formation of South Texas is indicated by its lateral continuation with the Sligo formation of East Texas; by its position immediately beneath the Pine Island shale member of the Pearsall of upper Aptian age, and by its similarity lithologically and stratigraphically to lower Aptian beds in northern Mexico. The only significant fossil reported from it in South Texas is *Orbitolina texana* (Roemer), from cuttings in the Humble Oil and Refining Company's R. L. Anderson No. 1, southern Uvalde County. This occurrence should be checked, as the species has not been found below the Rodessa formation in Louisiana. However, it has been reported from the upper part of the Travis Peak formation in central Texas.[18] Its occurrence in beds of Aptian age in the Tehuacán-San Juan Raya area of southeastern Puebla, Mexico, has been reported by Mullerried.[19] The presence of *Prochelonicreas* in the Dixie Oil Company's Dillon well No. 43,[20] located in Sec. 13, T. 21 N., R. 15 W.,

[18] Robert H. Cuyler, "Travis Peak Formation of Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 5 (1939), p. 637.

[19] F. K. G. Mullerried, "Estudios paleontológicos y estratigráficos en la región de Tehuacán, Puebla," *Anales Inst. Biología México*, t. 5, no. 1 (1934), pp. 64, 68.

[20] Gayle Scott, "Cephalopods from the Cretaceous Trinity Group of the South-Central United States," *Univ. Texas Pub. 3945* (1940a), pp. 976, 1002.
R. T. Hazzard, "Notes on the Comanche and Pre-Comanche? Mesozoic Formations of the Ark-La-Tex Area, and a Suggested Correlation with Northern Mexico," *Guide Book Fourteenth Ann. Field Trip Shreveport Geol. Soc.* (1939), p. 159.

Caddo Parish, Louisiana, is suggestive of a lower Aptian age, although the genus ranges up to the basal Albian.

Comparisons with outcrops in northern Mexico show that the Sligo formation of South Texas is remarkably similar to the lower member of the Cuchillo formation[21] of eastern Chihuahua. The latter consists of 700 to 1,500 feet of interbedded gypsum, dolomite, limestone and shale, underlies about 500 feet of shale and shaly limestone of upper Aptian age, and overlies a thick sequence of sandstone and shale similar to the Hosston formation. The best known occurrences of the gypsiferous lower member of the Cuchillo formation are in the Cuchillo Parado, Placer de Guadalupe, and Santa Elena districts. It is replaced stratigraphically in rather short distances by arkose and varicolored shale,[22] whose best known occurrences are in the Sierra Mojada of easternmost Chihuahua, at Barrill Viejo and Valle de Muralla in east-central Coahuila, and in the Sierra del Carmen of northwestern Coahuila. Evidently both the gypsiferous and arkosic facies were laid down on the margin of the Coahuila platform during lower Aptian time. Probably the arkosic facies was deposited near local uplifts and the gypsiferous facies in the intervening basins.

PEARSALL FORMATION

Definition.—The Pearsall formation is herein defined for a sequence of dominantly shaly beds lying above the Sligo formation and below the Glen Rose limestone, and representing the subsurface equivalents of the Travis Peak formation of the outcrop. The Amerada Petroleum Corporation's Halff and Oppenheimer No. 8, located in the Pearsall field, about 10 miles southwest of Pearsall, Frio County, Texas, is designated the type well. The type section is 525 feet thick, extending from about 8,835 to 9,369 feet, and is divisible into three members. The lower member is about 100 feet thick; consists of calcareous black shale interbedded with some hard, black, gray to light brown, dense to finely crystalline limestone; occupies the same stratigraphic position as the Pine Island shale of the Arkansas-Louisiana-East Texas area; and is considered equivalent to the basal gravel and sand of the Travis Peak formation of the outcrop. The middle member of the type section is about 85 feet thick; consists of black, gray to light brown, hard, dense to finely crystalline, fossiliferous limestone interbedded with minor amounts of calcareous black shale; and occupies the same stratigraphic position as the Cow Creek limestone member of the Travis Peak formation of the outcrop and

[21] R. H. Burrows, "Geology of Northern Mexico," *Bol. Soc. Geol. Mexicana*, T. 7 (1910), pp. 95, 96.
Carlos Burckhardt, "Étude synthétique sur le Mésozoique méxicain," *Soc. Paléon., Suisse Mém.*, Vols. 49, 50 (1930), p. 148.
R. W. Imlay, *op. cit.* (1944), pp. 1092, 1172, 1173, 1185.

[22] R. W. Imlay, *op. cit.* (1944), p. 1170.
Carlos Burckhardt, *op. cit.* (1930), p. 146.
R. W. Imlay, *op. cit.* (1940b), p. 121.
Emil Böse, "Vestiges of an Ancient Continent in Northeast Mexico," *Amer. Jour. Sci.*, 5th Ser., Vol. 6 (1923), p. 133.

as the James and Dierks limestones of the Arkansas-Louisiana-East Texas area. The upper member (Hensell shale member) of the type section is about 340 feet thick, consists of calcareous black shale interbedded with considerable black to dark gray shaly limestone and hard, dense, partly fossiliferous, black to light brown limestone, or, less commonly, light gray to white chalky limestone; and occupies the same stratigraphic position as the Hensell sand member of the Travis Peak formation. It is not certain that the Cow Creek limestone member of the Pearsall of South Texas is laterally continuous with the James and Dierks limestones of the Arkansas-Louisiana-East Texas area, but the term Pearsall formation can probably be employed usefully in the East Texas basin west of the Sabine uplift, as indicated particularly by the section at depths of 5,100 to 5,645 feet in the Magnolia Petroleum Company's Hull well No. 2, located about 5 miles east of Carthage, Panola County, Texas.

Distribution and thickness.—The Pearsall formation is probably nearly coextensive areally with the Comanche series in South Texas, considering that its surface equivalent, the Travis Peak formation, is the oldest Cretaceous exposed in the Central Mineral Region. The thickness of the Pearsall formation ranges from about 170 to 570 feet and averages about 350 feet. There may be as much as 1,030 feet in the Pure Oil Company's Smyth No. 1, Uvalde County, but available records concerning that well are not reliable for beds older than the Glen Rose limestone. The Pine Island shale member of the Pearsall ranges in thickness from 80 to 240 feet, the Cow Creek limestone member from 45 to 190 feet, and the Hensell shale member from 25 to 340 feet. At the outcrop in the Central Mineral Region the basal conglomerate and sandstone of the Travis Peak formation ranges in thickness from 50 to 125 feet, the Cow Creek limestone member from 30 to 78 feet and the Hensell sand member from 40 to 183 feet.[23]

Stratigraphic and lithologic features.—The Pearsall formation consists mainly of dark gray to black shale interbedded with some gray, brown or black shaly limestone, but contains medially a hard, fossiliferous limestone member that is generally thinner than the adjoining shale members. These members, from base to top, are designated the Pine Island shale member, the Cow Creek limestone member, and the Hensell shale member. The Pine Island shale member consists mostly of splintery black shale very similar to the Pine Island shale of the Arkansas-Louisiana-East Texas area. The Cow Creek limestone member is very similar to the Cow Creek at the outcrop. The Hensell shale member contains much more limestone than the Pine Island shale member, and in some sections contains sandstone at the top. It is much more shaly than the Hensell sand member of the Travis Peak of the outcrop.

The contact of the shales of the Pearsall with the hard limestones of the Sligo formation is very abrupt, easily recognized in samples and in electric logs, and marks a sudden change in sedimentation produced by an advance of the sea over

[23] R. H. Cuyler, "Travis Peak Formation of Central Texas," *Bull. Amer. Assoc. Petrol. Geol.* Vol. 23 (1939), pp. 630–35.

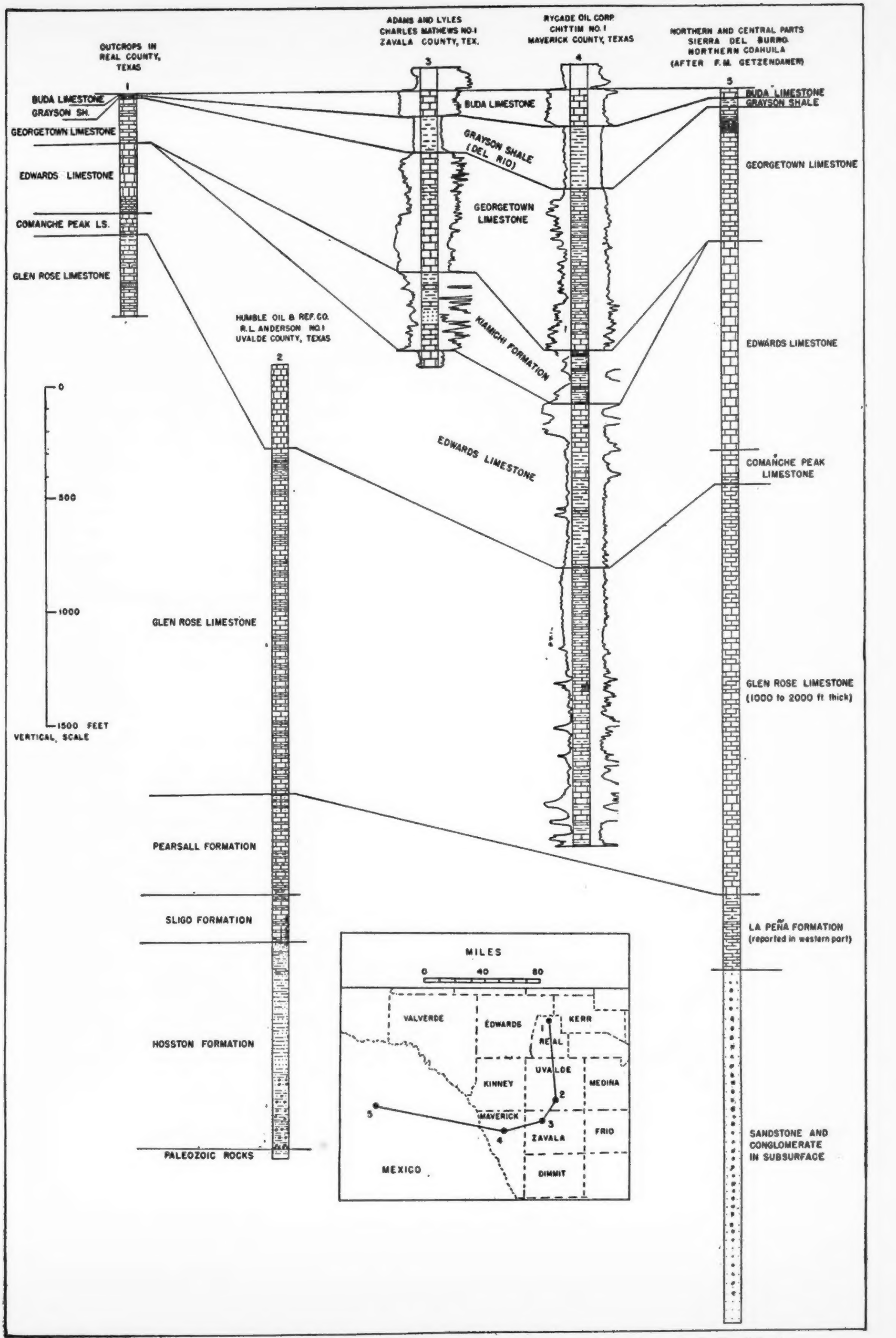


FIG. 5.—Columnar sections from Real County, Texas, to Sierra del Burro of northern Coahuila, Mexico.

the Central Mineral Region and other landmasses at the beginning of upper Aptian time. As there is a similar abrupt lithologic contact at the same stratigraphic position over much of northern and eastern Mexico, it is evident that the change in sedimentation was regional, and, therefore, that the top of the Sligo formation is an excellent horizon for mapping regional structure. No evidence of a disconformity at the Pearsall-Sligo contact has been found. Furthermore, the transgressive character of the upper Aptian deposits in the western part of the Gulf region shows the improbability of a disconformity at that position.

The contact of the subsurface Hensell shale member of the Pearsall with the overlying Glen Rose limestone is apparently gradational. However, a minor disconformity may occur locally within the Hensell as indicated (1) by marked differences in thickness of the member in the various well sections, (2) by conglomeratic beds at the top of the sands of the Hensell at the outcrop,[24] and (3) by the relationships of equivalent beds in the Arkansas-Louisiana-East Texas area, as discussed under correlation.

The characteristics of the Pearsall formation in South Texas and of equivalent beds in eastern Texas and northern Coahuila are shown in the following sections.

PEARSALL FORMATION IN AMERADA PETROLEUM CORPORATION'S HALFF AND OPPENHEIMER NO. 8, ABOUT 10 MILES SOUTHWEST OF PEARSALL, FRIO COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Hensell shale member		
Limestone, hard, dense to finely crystalline, mostly dark gray to black, some brown; a little pyrite; fossiliferous	8,835–8,890	55
Limestone, mostly hard, dense to finely crystalline, mostly dark gray, black, or brownish, some light gray to tan and fossiliferous; traces of chalky and oölitic limestone	–8,905	15
Limestone, hard, dense, partly shaly, dark gray, black, and brownish black, fossiliferous; considerable calcareous, black shale	–8,968	63
Shale, calcareous, dark gray to black; some gray and brown limestone.	–9,030	62
Limestone, shaly, dense to finely crystalline, dark gray to black, some brown to tan; some calcareous, splintery black shale	–9,065	35
Limestone, hard, dense to finely crystalline, gray to tan; about 35 per cent black shale and 5 per cent black, shaly limestone	–9,075	10
Shale, black, calcareous, and gray to black shaly limestone; some gray to tan limestone	–9,120	45
Shale, black, calcareous, hard; some dark gray limestone and traces of gray to tan limestone	–9,175	55
Cow Creek limestone member		
Limestone, hard, dense to finely crystalline, black, gray to light brown, fossiliferous, interbedded with minor amounts of calcareous black shale	–9,260	85
Pine Island shale member		
Limestone as above, plus considerable black shale	–9,280	20
Shale, black, and limestone, gray to tan, in about equal amounts; small amounts of dark gray to brown, sugary limestone	–9,305	25
Shale, black, calcareous, brittle; about 30 per cent hard, dense to finely crystalline, gray to tan limestone	–9,360	55
Total thickness		525

[24] J. A. Taff, "Report on the Cretaceous Area North of the Colorado River," *Texas Geol. Survey 3rd Ann. Rept.* (1892), p. 295.
R. H. Cuyler, *op. cit.* (1939), pp. 629, 634.

PEARSALL FORMATION IN HUMBLE OIL AND REFINING COMPANY'S R. L. ANDERSON NO. 1, ONE MILE EAST OF UVALDE, UVALDE COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Hensell shale member		
Limestone, slightly sandy, tannish gray; some gray sandstone; a little gray shale; contains oyster shell fragments and *Orbitolina texana* (Roemer) in cuttings	1,900–1,970	70
Cow Creek limestone member		
Limestone, tan	–2,040	70
Limestone, gray, slightly glauconitic	–2,080	40
Limestone, tan; *Orbitolina texana* (Roemer) reported in cuttings	–2,100	20
Limestone, gray	–2,160	60
Pine Island shale member		
Limestone, partly shaly, light gray, interbedded with some gray shale.	–2,260	100
Limestone, gray, partly glauconitic, interbedded with considerable gray shale	–2,300	40
Shale and limestone interbedded, gray	–2,340	40
Total thickness		440

PEARSALL EQUIVALENTS IN STANOLIND OIL AND GAS COMPANY'S TENNIE NORRIS NO. 1, LIMESTONE COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Hensell equivalents		
Limestone, granular to dense, gray, pseudo-oölitic	5,155–5,165	10
Sandstone, fine-grained, and siltstone, hard, greenish white calcareous.	–5,175	10
Shale, splintery, greenish gray	–5,180	5
James limestone (Cow Creek equivalent)		
Limestone, granular, pseudo-oölitic, slightly pyritic, gray; contains fossil shells	–5,195	5
Shale, splintery, slightly calcareous, dark gray, interbedded with mottled gray, pyritic granular limestone that contains fossil shells; a little sandstone present	–5,240	45
Pine Island shale		
Shale, splintery, greenish gray, slightly calcareous to noncalcareous...	–5,295	55
Shale, splintery, black, lignitic, non-calcareous; some greenish gray...	–5,325	30
Limestone, dense to granular, medium to dark gray, slightly oölitic; contains fossil shells; some dark shaly limestone	–5,335	10
Shale, splintery, greenish gray to black, pyritic; some thin beds of hard, gray, pyritic shaly limestone	–5,380	45
Total thickness		225

In the Magnolia Petroleum Company's Hull well No. 2, Panola County, the three members of the Pearsall formation, are easily recognizable. The lower 130 feet of black shale belong to the Pine Island shale member, the overlying 145 feet of brownish gray limestone belong to the Cow Creek limestone member (James limestone), and the next overlying 275 feet of gray shale occupies the same stratigraphic position as the Hensell shale member of the Pearsall formation. Above follows 105 feet of sandy limestone and shale, known as the Hill sandy lentil, which passes northward into the outcropping Ultima Thule gravel member of the Holly Creek formation in southern Arkansas, and is considered equivalent to the conglomeratic beds at the top of the outcropping Hensell sand member of the Travis Peak formation in central Texas.

PEARSALL EQUIVALENTS IN MAGNOLIA PETROLEUM COMPANY'S R. A. HULL NO. 2, PANOLA COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Limestone, sandy, and sandy shale	4,990–5,040	50
Limestone, gray to tan	–5,065	25
Shale, sandy, gray, calcareous	–5,085	20
Limestone	–5,095	10
Shale, splintery, gray; a few thin beds of dark gray shaly limestone	–5,370	275
Limestone, brownish gray to dark gray; some shaly limestone	–5,515	145
Shale, mostly black	–5,645	130
Total thickness		655

LA PEÑA FORMATION (PEARSALL EQUIVALENT) IN OHIO MEXICAN OIL CORPORATION'S CLOETE NO. 1, COAHUILA, MEXICO

	Depth in Feet	*Thickness in Feet*
Shale, black; some dark brown limestone; contains *Globigerina* and fish remains	2,640–2,930	90
Limestone, brown, and black shale; contains *Globigerina*	–2,990	60
Limestone, finely crystalline, light brown	–3,000	10
Limestone, dark brown, and some black shale; contains Miliolidae	–3,060	60
Total thickness		420

Correlation.—The Pearsall formation of South Texas has not furnished any significant fossils. Its age determination is based (1) on the occurrence of *Dufrenoya* in the Cow Creek limestone member of the Travis Peak on the outcrop,[25] (2) on its stratigraphic position beneath the Glen Rose limestone of lower and middle Albian age, and (3) on the fossils that have been found in stratigraphically equivalent beds in Mexico and in the Arkansas-Louisiana-East Texas area.

The Pearsall formation appears to be equivalent to the shaly and thin-bedded limestones constituting the upper member of the La Peña formation in north-central Mexico,[26] the Otates beds of eastern Mexico,[27] and the upper member the Cuchillo formation of eastern Chihuahua.[28] As these Mexican equivalents are mainly of upper Aptian age but include at their top the basal Albian zone of *Diadochoceras nodosocostatum* (D'Orbigny),[29] it seems probable that the Hensell shale member of the Pearsall formation is at least partly of basal Albian age.

[25] Carlos Burckhardt, "Faunas del Aptiano de Nazas (Durango)," *Bol. Inst. Geol. México*, Núm. 45 (1925), p. 17.
Gayle Scott, "Études stratigraphiques et paléontologiques sur les terrains crétacés du Texas," Thèse, *Université de Grenoble* (1926a), p. 119.
———, "Cephalopods from the Cretaceous Trinity Group of the South-Central United States," *Univ. Texas Pub. 3945* (1940a), pp. 1022–24.

[26] R. W. Imlay, "Studies of the Mexican Geosyncline," *Bull. Geol. Soc. America*, Vol. 49 (1938), pp. 1689, 1690.

[27] John M. Muir, *Geology of the Tampico Region, Mexico*, Amer. Assoc. Petrol. Geol. (1936), pp. 27, 28.

[28] R. H. Burrows, *op. cit.*, pp. 75, 76.

[29] Carlos Burckhardt, "La faune jurassique de Mazapil avec un appendice sur les fossiles du Crétacique inférieur," *Bol. Inst. Geol. México*, Núm. 23 (1906), pp. 197, 198.
———, "Faunas del Aptiano de Nazas (Durango)," *ibid.*, Núm. 45 (1925), pp. 49–53.
———, *op. cit.* (1930), p. 134.

Beds equivalent to the Pearsall formation in the subsurface of the Arkansas-Louisiana-East Texas area include, from base to top, the Pine Island shale, the James limestone, and the overlying Rodessa formation as high as the top of the unit known informally as the Hill sandy lentil. The equivalent beds outcropping in Sevier, Howard, and Pike counties, Arkansas, include from base to top the Pike gravel, the Delight sand (here proposed), the Dierks limestone, and the Holly Creek formation. The last named includes the Ultima Thule gravel member in its lower part. The stratigraphic relationships of these surface and subsurface units is strikingly similar to that in South Texas between the units of the subsurface Pearsall formation and the units of the surface Travis Peak formation, as discussed later.

The term Delight sand is herein proposed for sand lying between the Pike gravel and the Dierks limestone in Sevier, Howard, and Pike counties, Arkansas.[30] The Delight sand is gray, generally fine-grained and cross-bedded, thick-bedded, interbedded with some clay, and is locally impregnated with asphalt. It attains a thickness of at least 200 feet in the area between Delight and Pike and thins westward. The asphalt quarry just west of Wolf Creek and about $3\frac{3}{4}$ miles northwest of Delight has excellent exposures of the sand and is designated the type locality. The Delight sand and the underlying Pike gravel[31] are the lowest rocks of the Comanche series on the outcrop in Arkansas. They pass southward in the subsurface into the Pine Island shale, which is of upper Aptian age and lies far above the base of the Lower Cretaceous.[32] Some gelogists have argued that the Pike gravel is equivalent to most of the subsurface Lower Cretaceous section older than the James limestone, but this seems unlikely to the writer, as most gravel deposits appear to have been deposited fairly rapidly, and there is much evidence that the Mexican and Gulf seas spread rapidly over bordering landmasses at the beginning of the upper Aptian.

The Pine Island shale is definitely upper Aptian in age, as cores from its upper part have furnished the ammonites *Dufrenoya, Hypacanthoplites, Parahoplites?* and *Pseudosaynella*.[33] The occurrence of either *Dufrenyoa* or *Pseudosaynella* justifies assigning the shale to the upper Aptian.

It is now generally agreed that the James limestone is the subsurface equivalent of the Dierks limestone of the outcrop in southern Arkansas.[34] The Dierks limestone generally has been considered Glen Rose in age on the basis of studies

[30] Hugh D. Miser and A. H. Purdue, "Geology of the DeQueen and Caddo Gap Quadrangles, Arkansas," *U. S. Geol. Survey Bull. 808* (1929), p. 84, Pl. 5 opp. p. 28, and Pl. 3.

[31] *Ibid.*, pp. 81, 82.

[32] Imlay, *op. cit.* (1940a), pp. 32, 33, 58.

[33] Hazzard, *op. cit.* (1939), pp. 159–62.

[34] Warren B. Weeks, "South Arkansas Stratigraphy with Emphasis on the Older Coastal Plain Beds," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22 (1938), p. 970.
Imlay, *op. cit.* (1940a), p. 34.

of its pelecypods.[35] Stanton[36] considered that rocks of Travis Peak age probably did not occur as far north as Arkansas and Oklahoma. However, the presence of a fragmentary ammonite belonging to the genus *Pseudosaynella* influenced Scott[37] to regard the Dierks limestone as upper Aptian in age. His assignment is now confirmed by (1) additional discoveries of well preserved specimens of *Pseudosaynella* in the Dierks limestone, (2) by the association of *Pseudosaynella* with *Dufrenoya* in the upper part of the Pine Island shale directly below the James limestone in the sursurface of northern Louisiana, and (3) by the association of *Pseudosaynella* with *Dufrenoya* in the Cow Creek limestone member of the Travis Peak of the Central Mineral Region.[38] In Europe neither *Pseudosaynella* or *Dufrenoya* has been recorded above the Aptian, and *Pseudosaynella* has been recorded only from the upper Aptian. This faunal evidence indicating that the James and the Cow Creek were formed contemporaneously, or nearly so, in upper Aptian time is strengthened by the absence of *Orbitolina* from the Dierks, James, and Cow Creek strata although present in the overlying beds. Furthermore, the study of many dip sections demonstrates that the James and Cow Creek strata occupy the same relative positions with respect to adjoining formations.

The Holly Creek formation passes in the subsurface into the lower and middle parts of the Rodessa formation. The upper part of the Holly Creek formation passes southward into the unit known informally as the Hill sandy lentil of the Rodessa. Probably the Ultima Thule gravel member of the Holly Creek corresponds with the base of the Hill sandy lentil. The lower part of the Holly Creek formation passes southward over the area of the Sabine uplift into a dominantly limestone section, in which at present local geologists recognize the following informal units, from top to bottom: a thin anhydrite tongue, the Gloyd limestone lentil, the Dees sandy limestone lentil, and the Young limestone lentil. These units pass eastward into sandstone and shale and westward into shale similar lithologically and stratigraphically to the Hensell shale member of the Pearsall formation of South Texas. Their age is probably lower Albian rather than upper Aptian, as they overlie a considerable thickness of beds of upper Aptian age and contain *Orbitolina*, which is uncommon below the Albian in the Gulf region.

[35] T. W. Stanton in Miser and Purdue, *op. cit.*, pp. 85, 86.
H. C. Vanderpool, "Fossils from the Trinity Group (Lower Comanchean)," *Jour. Paleon.*, Vol. 2, No. 2 (1928b), pp. 95–107.

[36] T. W. Stanton, "The Lower Cretaceous or Comanche Series," *Amer. Jour. Sci.*, 5th Ser., Vol. 16 (1928), p. 403.

[37] Gayle Scott, "Études stratigraphiques et paléontologiques sur les terrains crétacés du Texas," *Thèse, Université de Grenoble* (1926a), p. 39.
———, "Cepolopods from the Cretaceous Trinity Group of the South-Central United States," *Univ. Tex. Pub. 3945* (1940a), pp. 998, 999.

[38] Robert Cuyler in W. S. Adkins, "The Mesozoic Systems in Texas," in "The Geology of Texas, Vol. 1, Stratigraphy," *Univ. Texas Bull. 3232* (1933), p. 315.
H. G. Damon and G. R. McNutt, "Cretaceous in the Vicinity of Austin," *Excursion Guide of the Geol. Soc. America, 53d Ann. Meeting* (1940), p. 9.

The sequence of units in the Rodessa formation suggests that its lower part was deposited in a regressive sea, and its upper part, beginning with the Hill sandy lentil, in a transgressive sea. This is indicated (1) by the overlapping of the Ultima Thule gravel member of the Holly Creek onto the Pike gravel, or onto Carboniferous rocks near the Oklahoma-Arkansas state line,[39] (2) by the variable thickness of the lower part of the Rodessa formation in the area along the Arkansas-Louisiana state line, suggesting a brief interval of erosion, or non-deposition, just prior to the deposition of the Hill sandy lentil,[39a] and (3) by the wide distribution of the Hill sandy lentil, suggesting a marked shift in relative position of land and sea. As the stratigraphic position of the Hill sandy lentil appears to be the same as the conglomeratic beds at the top of the Hensell sand member of the Travis Peak of the Central Mineral Region, a minor disconformity within the Hensell and its equivalents may be widespread.

GLEN ROSE LIMESTONE

Distribution and thickness.—The Glen Rose limestone in the subsurface of South Texas is practically co-extensive with the Comanche series. Its thickness, as recorded from 16 wells, ranges from 460 to 1,843 feet and increases markedly basinward. In comparison, its thickness on the outcrop in South Texas ranges from about 50 to nearly 800 feet.

Stratigraphic and lithologic features.—The Glen Rose limestone in the subsurface of South Texas consists of a monotonous sequence of hard gray and tan to dark brown limestone. It is generally dense to finely crystalline, but some beds are granular, or sugary, or oölitic. Shale and shaly limestone occur commonly near the top and bottom of the formation. Silty beds or disseminated sand grains occur commonly in the upper 100 feet. In northern Coahuila, beds of sandstone appear to be fairly common in the lower part of the formation but have not been reported in Texas. Anhydrite, in granules, pockets, and thin beds, occurs throughout but does not form a conspicuous zone comparable to the Ferry Lake anhydrite of the Arkansas-Louisiana-East Texas area or to the 17 feet of gypsum 150 feet above the base of the Glen Rose limestone as exposed on East Frio River in Real County, Texas. Microfossils and fragments of shells are common. Contacts with adjoining formations in the subsurface appear to be conformable, although the possibility of minor disconformities in marginal areas should not be excluded.

Cuyler[40] points out that the Glen Rose limestone overlaps the Travis Peak formation northward from Comal County to Burnet County and that "the base of the Glen Rose in Burnet County corresponds approximately with the middle of the section in Comal County." If an unconformity of such magnitude exists

[39] Hugh D. Miser, "Lower Cretaceous (Comanche) Rocks of Southeastern Oklahoma and Southwestern Arkansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 448, 449.
Miser and Purdue, *op. cit.*, p. 82.

[39a] Roy T. Hazzard, personal communication.

[40] *Op. cit.* (1939), pp. 635, 639.

on the surface, an important unconformity should likewise be present in the subsurface and might be of economic significance. In this regard Adkins[41] noted "it is probable that the reduced outcrop thickness represents only the upper portion of the complete formation." However, Adkins probably then included in the Glen Rose limestone the beds now assigned to the Pearsall and Sligo formations. As previously discussed, a disconformity within the Hensell shale member of the Pearsall formation seems possible.

As compared with the outcrops of the Glen Rose limestone in South Texas,[42] the subsurface Glen Rose limestone is generally thicker, harder, darker, and less shaly. The upper 100 feet of shaly beds containing scattered sand grains passes northward at the outcrop in Real and adjoining counties into about 100 feet of soft, sandy limestone and shale. Likewise the basal shaly beds of the Glen Rose limestone becomes sandier toward the outcrop along the southern margin of the Edwards Plateau, and, in places, the entire formation becomes sandy, as well illustrated by Barnes[43] for Gillespie County.

The characteristics of the subsurface Glen Rose limestone are illustrated by the following sections in South Texas and northern Coahuila.

Glen Rose Limestone in Amerada Petroleum Corporation's Halff and Oppenheimer No. 8, about 10 Miles Southwest of Pearsall, Frio County, Texas

	Depth in Feet	*Thickness in Feet*
Glen Rose formation		
Limestone, brown to black, hard, finely crystalline to dense; some brown, soft to hard, sugary limestone and light gray, hard, dense limestone; trace of gray shale	6,992–7,040	48
Limestone, light tan, miliolid-bearing; a little brown to black, dense limestone	–7,060	20
Limestone, tan and brown, hard, dense to finely crystalline; traces of cherty limestone and soft, chalky white limestone; trace of anhydrite at depth of 7,110 feet	–7,120	60
Limestone, tan and gray, hard, dense to finely crystalline; some brown, porous sugary limestone; traces of cream to white, porous limestone	–7,190	70

[41] *Op. cit.* (1933), p. 317.

[42] W. S. Adkins, *op. cit.* (1933), pp. 297, 298, 309, 317.
Lon D. Cartwright, Jr., "Regional Structure of Cretaceous on Edwards Plateau of Southwest Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16 (1932), pp. 692, 693.
R. T. Hill and T. W. Vaughan, "Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Texas, with Reference to the Occurrence of Underground Waters," *U. S. Geol. Survey Ann. Rept. 18*, Pt. 2 (1898), pp. 221, 314.
J. A. Taff, *op. cit.* (1892), pp. 289–300.
F. M. Getzendaner, "Geologic Section of Rio Grande Embayment, Texas, and Implied History," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), pp. 1425, 1426.
———, "Mineral Resources of Texas: Uvalde, Zavala, and Maverick Counties," *Univ. Texas Bur. Econ. Geol.* (1931), pp. 95, 97.
E. H. Sellards, "The Geology and Mineral Resources of Bexar County," *Univ. Texas Bull. 1932* (1920), pp. 23, 24.
A. N. Sayre, "Geology and Ground Water Resources of Uvalde and Medina Counties, Texas," *U. S. Geol. Survey Water-Supply Paper 678* (1936), pp. 39, 40.

[43] V. E. Barnes, "Pre-Cambrian of Llano Region with Emphasis on Tectonics and Intrusives," *Excursion Guide of the Geol. Soc. America, 53d Ann. Meeting* (1940), pp. 48, 52.

	Depth in Feet	*Thickness in Feet*
Limestone, tan to brown, hard, dense to finely crystalline; trace of white, fossiliferous limestone	−7,250	60
Limestone, gray to brown, dense to finely crystalline, very hard; a little light gray fossiliferous limestone; some oölites at base	−7,280	30
Limestone, gray, tan, and brown, with some white spots; small amount of hard, sugary limestone, slightly fossiliferous; some black shaly limestone; trace of anhydrite at depth of 7,310 feet	−7,315	25
Limestone, gray to tan, very hard, dense to finely crystalline some light gray, fossiliferous limestone; trace of black shaly limestone	−7,348	33
Limestone, dark gray to brown, hard, mostly dense to finely crystalline; traces of white limestone and black shaly limestone; trace of anhydrite	−7,440	92
Limestone, brown, dense; some tan, fossiliferous limestone; trace of black limestone; trace of anhydrite	−7,490	50
Limestone, tan to brown, hard, dense to finely crystalline; some sugary, some fossiliferous limestone; some dolomite crystals	−7,550	60
Limestone, gray to tan, rarely brown, hard, dense to finely crystalline; trace of anhydrite	−7,600	50
Limestone, gray, tan, and brown, hard, dense; some light gray to buff, porous limestone; traces of anhydrite	−7,700	100
Limestone, gray to tan, dense to finely crystalline to fairly porous; some black shaly partings and anhydrite inclusions	−7,758	58
Limestone, dark brown, mostly dense, some gray and fossiliferous; traces of anhydrite; highest occurrence of *Orbitolina texana* (Roemer) noted at 7,805 feet	−8,060	302
Limestone, light gray to buff, fairly porous; some dark, dense limestone	−8,110	50
Limestone, mostly dark brown and dense, some light gray; trace of black shaly limestone	−8,150	40
Limestone, gray, hard, dense to finely crystalline; trace of dark limestone	−8,180	70
Limestone, mostly dark gray to brown, hard, dense to finely crystalline; some gray to tan	−8,400	220
Limestone, mostly light gray to buff and tan, dense to finely crystalline; some dark gray to brown	−8,460	60
Limestone, tan, gray, brown, dense, hard	−8,493	36
Limestone, partly dark gray to black, hard, dense; partly buff, soft to medium hard; some black shale and anhydrite inclusions	−8,590	97
Limestone, mostly dark gray, brown, and black, hard, dense; some gray to buff; trace white, chalky limestone; some shaly limestone	−8,835	245
Total thickness		1,834

INCOMPLETE SECTION OF GLEN ROSE LIMESTONE IN WELLINGTON OIL COMPANY'S J. M. CHITTIM ESTATE NO. 1-A, MAVERICK COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Limestone, dark brown and tan, hard, dense, fossiliferous	4,725–4,765	40
Limestone, as above but including some white, granular anhydrite and dark gray to greenish gray shale	−5,039	274
Limestone, dense, dark brown, fossiliferous; some light tan and oölitic; some anhydrite and dark gray to greenish gray shale; first appearance of *Orbitolina texana* (Roemer) noted at depths of 5,049–5,059 feet	−5,270	231
Anhydrite, hard, dense, white; contains a few streaks of dense, brown limestone	−5,285	15
Limestone, grayish brown to tan, dense to finely crystalline, fossiliferous	−5,489	204
Limestone, dark brown, dense; some dark gray to greenish gray, brittle shale; fossiliferous	−5,718	229
Limestone, dark brown to tan, dense, fossiliferous; anhydrite common	−5,739	19
Limestone, dark brown; some grayish tan, dense; a little black shale, trace of anhydrite	−5,849	110
Limestone, grayish tan, hard, dense to fairly porous	−5,891	42
Total thickness		1.166

GLEN ROSE LIMESTONE IN HUMBLE OIL AND REFINING COMPANY'S
R. L. ANDERSON NO. 1, UVALDE COUNTY, TEXAS

	Depth in Feet	Thickness in Feet
Limestone, brown, brownish gray, light tannish gray, finely crystalline; some oölitic or argillaceous, limestone; a little gray shale	370–420	50
Shale, in part very finely sandy, medium gray; some tan limestone	–430	10
Limestone, partly soft and marly, partly hard and brownish gray	–440	10
Shale, gray	–460	20
Shale and marl, brown to gray, finely laminated; some brown limestone	–485	25
Limestone, light gray, finely crystalline; some brown shale and limestone in upper 20 feet	–600	115
Limestone, light gray, slightly oölitic, fossiliferous	–760	160
Limestone, light gray to tannish gray, slightly granular, fossiliferous	–860	100
Limestone, light gray, finely crystalline; white anhydrite common	–880	20
Limestone, light gray, finely crystalline to slightly granular, oölitic, fossiliferous; a few thin seams of marl and shale; first, appearance of *Orbitolina texana* (Roemer) at depths of 1,040–1,060 feet	–1,100	220
Limestone, medium to light gray, oölitic, fossiliferous; some thin seams of marl and shale; *Orbitolina texana* (Roemer) abundant	–1,440	340
Limestone, light tan to tannish gray, finely crystalline to slightly granular, or finely oölitic; a few thin seams of marl; fossiliferous	–1,840	400
Limestone, light gray and brownish gray, slightly oölitic to slightly granular; fossiliferous	–1,900	60
Total thickness		1,530

Some geologists consider that the shaly beds at depths of 370 to 485 feet represent the Comanche Peak limestone. However, shaly beds, in part finely sandy, as at depths of 430 to 440 feet, are characteristic of the highest part of the Glen Rose limestone of South Texas and are probably equivalent to the Paluxy sand farther north. Also, some tannish gray chalky limestones at depths of 280 to 370 feet are lithologically more like the outcropping Comanche Peak limestone in Uvalde and Real counties than are the shaly beds below 370 feet.

GLEN ROSE LIMESTONE IN OHIO MEXICAN OIL COMPANY'S
CLOETE NO. 1, NORTHERN COAHUILA, MEXICO

	Depth in Feet	Thickness in Feet
Limestone, light tan, granular	1,015–1,100	85
Limestone, brown to grayish brown, mostly finely crystalline; some granular	–2,160	1,060
Limestone as above, with some calcareous, black shale throughout; considerable black shale noted at depths of 2,500 to 2,540 feet and 2,610 to 2,640 feet	–2,640	480
Total thickness		1,625

Possibly the upper 85 feet of the foregoing section belongs in the Fredericksburg group. However the depth of 1,015 feet was selected as the top of the Glen Rose limestone (1) because of the driller's record of 15 feet of gray shale at depths of 1,000 to 1,015 feet, (2) by comparison with the formation tops in the American Smelting and Refining Company's Las Uvas No. 1 well, and (3) in consideration of the thickness of Fredericksburg rocks exposed in the Burro Mountains to the south. The driller's log of the Cloete well No. 1 lists gray and brown sandstone at depths of 1,325–1,355, 2,035–2,052, 2,091–2,100, 2,109–2,145, 2,225–2,237, and 2,331–2,339 feet. The presence of sandstone in the lower part of the Glen Rose limestone has also been recorded in the Ohio Mexican Oil Company's Zambrano

well No. 1, 33 miles west of Del Rio, Texas, and in San Vicente Canyon in the central part of the Burro Mountains. Concerning the last occurrence, F. M. Getzendaner[43a] notes that the Glen Rose limestone is more than 1,000 feet thick and probably includes some sandstones exposed near the base of the section.

GLEN ROSE LIMESTONE IN OHIO MEXICAN OIL COMPANY'S ZAMBRANO NO. 1, NORTHERN COAHUILA, MEXICO

	Depth in Feet	*Thickness in Feet*
Limestone, dark gray, medium hard	780–840	60
Limestone, sandy, gray	–850	10
Limestone, gray, medium hard	–980	130
Limestone, mostly dark gray, some light gray, medium hard; some beds are sandy	–1,600	620
Sandstone, fine-grained, gray and white, calcareous	–1,610	10
Limestone, dark gray, medium hard; minor amounts of sandy limestone; overlies 100 feet of soft, light to dark gray limestone which is probably equivalent to the Pearsall formation	–2,130	520
Total thickness		1,350

Correlation.—The only significant fossil reported from the Glen Rose limestone in the subsurface of South Texas is *Orbitolina texana* (Roemer), or closely related species. It is invariably absent from the upper 200 to 400 feet of the limestone, and in the Amerada's Halff and Oppenheimer well No. 8 it has not been recorded from the upper 800 feet. This corresponds well with surface outcrops in South Texas, where the genus is reported to be absent from the upper 200 to 300 feet of the Glen Rose limestone. However, *Orbitolina texana* (Roemer) has been reported on the outcrop from the upper part of the Hensell sand member of the Travis Peak formation[44] and from the Walnut clay.[45] In the subsurface of the Arkansas-Louisiana-East Texas area this species is reported to range from the base of the Rodessa formation into the Mooringsport formation. Glen Rose limestone, on the basis of stratigraphic position, must correspond to most, or all, of the lower Albian and the lower part of the middle Albian.

Correlation of the outcrop sections of the Glen Rose formation has been discussed by many geologists[46] and will not be treated here. In the subsurface of South Texas the Glen Rose limestone occupies the entire interval between the top of the Pearsall formation and the base of the Fredericksburg group. North of Robertson County in the subsurface of East Texas, the Glen Rose limestone passes into at least four major lithologic units, which extend into Arkansas and

[43a] Personal communication.

[44] R. H. Cuyler, *op. cit.* (1939), p. 637.

[45] R. Wright Barker, "Some Larger Foraminifera from the Lower Cretaceous of Texas," *Jour. Paleon.*, Vol. 18 (1944), p. 209.

[46] T. W. Stanton, "The Lower Cretaceous or Comanche Series," *Amer. Jour. Sci.*, 5th Ser., Vol. 16 (1928), pp. 403, 404.

H. C. Vanderpool, "A Preliminary Study of the Trinity Group in Southwestern Arkansas, Southeastern Oklahoma, and Northern Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12 (1928a), pp. 1076–89.

Adkins, *op. cit.*, pp. 295–322.

Scott, *op. cit.* (1940), pp. 971–81.

Louisiana. Near the top of the Glen Rose, beds of limestone pass northward into shale and sand which comprise the Paluxy formation. Near its base appears the Ferry Lake anhydrite, which separates the marine beds of the Mooringsport formation above from similar beds below that have considered the upper part of the Rodessa formation. This sequence, below the Paluxy formation, passes northeastward into the DeQueen limestone[47] at the outcrop in southern Arkansas, although probably the top of the DeQueen limestone is somewhat older than the top of the Mooringsport formation.

The Glen Rose limestone extends southward as far as the Burro Mountains of northern Coahuila, where it is represented by more than 1,000 feet of limestone and marl containing interbeds of sandstone basally and characterized by *Orbitolina texana* (Roemer). South of the Burro Mountains it passes into the rudistid-bearing Aurora limestone. Correlation of the Mexican equivalents of the Glen Rose limestone has been discussed in detail elsewhere.[48]

EDWARDS LIMESTONE, COMANCHE PEAK LIMESTONE, AND WALNUT CLAY

Distribution and thickness.—Limestones of the Fredericksburg group older than the Kiamichi formation have been penetrated by many wells in various parts of South Texas. Their thickness ranges from 200 to 825 feet and increases basinward. They are considerably thicker than equivalent beds in the East Texas basin, which are locally reduced to a thickness of 8 feet. Most of the thinning occurs north of Robertson County in East Texas proper. Equivalent beds in the northern part of the Burro Mountains in northern Coahuila are about 1,070 feet thick,[48a] of which about 150 feet belong to the Walnut clay and Comanche Peak limestone. Equivalent beds on the outcrop in South Texas range in thickness from about 370 to 780 feet, of which the lower 50 to 90 feet belong to the combined Walnut clay and Comanche Peak limestone.

Stratigraphic and lithologic features.—In sursurface studies of South Texas no distinction has been made between Walnut clay, Comanche Peak limestone, and Edwards limestone. According to current practice, they are all combined under the term Edwards limestone. Probably careful lithologic studies would make possible separation of the Comanche Peak from the Edwards, but the Walnut clay appears either to be absent or unidentifiable in well cuttings owing to extreme thinness. This corresponds with conditions on the outcrop in South Texas, where the Walnut clay is absent in some places and at others is so thin that in practice it is mapped with the overlying Comanche Peak limestone.[49]

[47] H. D. Miser and A. H. Purdue, "Geology of the De Queen and Caddo Gap Quadrangles, Arkansas," *U. S. Geol. Survey Bull. 808* (1929), p. 83.

[48] R. W. Imlay, "Cretaceous Formations of Central America and Mexico," *Bull. Amer. Assoc. Petrol. Geol.* Vol. 28 (1944), pp. 1093–95, 1182, Table I.

[48a] F. M. Getzendaner, personal communication.

[49] Adkins, *op. cit.*, pp. 332, 333.
H. G. Damon and G. R. McNutt, "The Cretaceous Formations in the Vicinity of Austin," *Excursions, 53d Ann. Meeting, Geol. Soc. America* (1940), p. 9.

The Edwards limestone of the subsurface consists mainly of hard, dense to coarsely crystalline gray to brownish black limestone. Some layers are soft and chalky. Other layers, particularly near the top of the formation, are very porous. Dolomite, dolomitic limestone, and anhydrite occur commonly, particularly in the lower part of the formation. The anhydrite does not form a thick, widespread layer comparable with the gypsum of the Kirschberg evaporite of Barnes[50] which is widespread in Gillespie and adjoining counties at a horizon a little below the middle of the Edwards limestone. Chert occurs in some beds. Microfossils are scarce or absent in some layers and abundant in others. Miliolids appear to be the most abundant fossils. Some layers contain shell fragments. Pyrite is fairly common.

The contact of the Edwards limestone with the overlying Kiamichi formation is sharp but apparently conformable. Where the Kiamichi formation has been removed by pre-Georgetown erosion, as on the San Marcos arch, the upper part of the Edwards limestone may be cavernous, and the contact with the Georgetown limestone is marked by a few feet of soft clay called "dobie" or "adobe,"[51] which consists of soft, yellowish, microscopic particles of dolomite, chalk, and limestone.

Some of the best known well sections follow.

EDWARDS AND COMANCHE PEAK LIMESTONES IN AMERADA PETROLEUM CORPORATION'S HALFF AND OPPENHEIMER NO. 8, FRIO COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Limestone, mostly hard, finely crystalline, light gray; some white with green specks; trace of soft, porous, brown limestone	6,210–6,223	13
Limestone, fairly soft, very porous, gray to black; some very soft, black and white, chalky limestone	–6,230	7
Limestone, light tan, fossiliferous; some porosity	–6,285	55
Limestone, medium soft, light tan to white, porous, coarsely crystalline; some hard, brown, and finely crystalline	–6,320	35
Limestone, light tan to white, porous, and coarsely crystalline; some tan to brown, and finely crystalline; considerable soft, light buff, chalky limestone in lower 10 feet	–6,340	20
Limestone, tan, oölitic, slightly porous, fossiliferous; some light tan to white and porous	–6,380	40
Limestone, tan to brown, non-porous, trace of chert	–6,393	13
Limestone, mostly light tan to white, porous, fossiliferous; some hard, dense gray to tan limestone; trace of chert	–6,420	27
Limestone, light brown, finely crystalline, fossiliferous, fairly porous; some hard, gray, and dense	–6,430	10
Limestone, tan, finely crystalline, slightly porous, with a trace of chert; small amount of soft, white, chalky limestone	–6,490	60
Limestone, light tan to brown, finely crystalline; considerable calcite; trace of chert; a little brown, granular limestone	–6,500	10

[50] V. E. Barnes, "Gypsum in the Edwards Limestone of Central Texas," *Univ. Texas Pub. 4301* (1944), pp. 35–46.

[51] Ernest W. Brucks, "The Luling Field, Caldwell and Guadalupe Counties, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), p. 645.

Richard A. Jones, "Subsurface Cretaceous Section of Southwestern Bexar County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), p. 770.

L. F. McCollum, C. J. Cunningham, and S. O. Burford, "Salt Flat Oil Field, Caldwell County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), p. 1408.

	Depth in Feet	Thickness in Feet
Limestone, hard, brown to tan, dense to finely crystalline, non-porous; trace of brown; fossiliferous limestone; trace of chert	–6,610	110
Limestone, hard, gray to tan, dense, partly fossiliferous; some calcite	–6,670	60
Limestone, hard, light buff, dense, fossiliferous; some cherty limestone; small amount of sugary, porous, brown limestone; trace of anhydrite	–6,680	10
Anhydrite mainly; some tan to brown, dense limestone	–6,700	20
Limestone, mostly light tan, slightly porous, fossiliferous; some tan and dense; about 10 per cent anhydrite	–6,710	10
Limestone as above, but with much brown, granular, porous limestone and some sugary, brown dolomite; about 15 per cent anhydrite	–6,780	70
Limestone, tan to brown, mostly dense to finely crystalline; some sugary; trace of anhydrite	–6,800	20
Limestone, light buff to cream, fossiliferous	–6,810	10
Limestone, hard, mostly tan to brown, dense to finely crystalline; some light buff to cream; trace of chert; some anhydrite	–6,860	50
Dolomite, hard, brown, sugary, porous; considerable tan to brown, dense to coarsely crystalline limestone	–6,900	40
Limestone, hard, tan to brown, porous, coarsely crystalline; some tan to cream, chalky limestone; trace of anhydrite	–6,950	50
Limestone, hard, mainly light tan; some brown, dense to finely crystalline; some chert and cherty limestone	–6,992	42
Total thickness		782

EDWARDS AND COMANCHE PEAK LIMESTONES IN WELLINGTON OIL COMPANY'S J. M. CHITTIM ESTATE NO. 1-A, MAVERICK COUNTY, TEXAS

	Depth in Feet	Thickness in Feet
Limestone, hard, dense, yellowish gray to grayish brown; some grayish tan, fossiliferous	4,075–4,090	15
Limestone, hard, dense to slightly porous, grayish tan to tan; contains abundant miliolids; some streaks of lignite	–4,130	40
Limestone, hard, dense, gray, brown to nearly black, calcitic	–4,170	40
Limestone, hard, dense, tan to dark brown; abundant miliolids	–4,179	9
Limestone, hard, tan and gray, dense to fairly porous; trace of anhydrite	–4,279	100
Limestone, hard, tan and brown, dense to finely crystalline, calcitic	–4,329	50
Limestone, hard, dark brown, dense, slightly pyritic; trace of hard, black, granular limestone; some gray shale	–4,429	100
Limestone as above, plus trace of anhydrite	–4,509	80
Limestone, hard, brown to tan, dense; some anhydrite	–4,559	50
Limestone, tan, dense to porous; some dark brown, pyritic limestone	–4,609	50
Limestone, hard, dark brown, dense; some black, granular limestone	–4,725	116
Total thickness		650

EDWARDS AND COMANCHE PEAK LIMESTONES IN OHIO MEXICAN OIL COMPANY'S ZAMBRANO NO. 1, NORTHERN COAHUILA, MEXICO

	Depth in Feet	Thickness in Feet
Limestone, hard, gray, pyritic	110–150	40
Limestone, hard, white, pyritic	–170	20
Limestone, hard, light gray, pyritic	–210	40
Limestone, hard, yellowish white, pyritic	–250	40
Limestone, hard, grayish white	–390	140
Limestone, hard, white	–420	30
Limestone, fairly soft, gray to white	–470	50
Limestone as above plus considerable hard, dark gray limestone; much chert	–500	30
Limestone, fairly soft, white	–600	100

	Depth in Feet	Thickness in Feet
Limestone, fairly soft, gray to white; considerable chert	-660	60
Limestone as above plus much hard gray limestone	-670	10
Limestone, fairly soft, yellowish white	-700	30
Limestone, medium hard, gray	-770	70
Limestone, medium soft, white to dark gray	-780	10
Total thickness		670

EDWARDS AND COMANCHE PEAK LIMESTONES IN RYCADE OIL CORPORATION'S SULLIVAN NO. 5, MAVERICK COUNTY, TEXAS

	Depth in Feet	Thickness in Feet
Limestone, dolomitic, light tannish gray to brown; some translucent anhydrite	3,540-3,600	60
Limestone, partly porous, dolomitic, dark brown to brownish gray, finely crystalline; some white anhydrite; contains miliolids	-3,638	38
Limestone, light gray, slightly porous; some brownish gray and dolomitic; some translucent anhydrite	-3,677	39
Limestone, gray, and anhydrite	-3,709	32
Limestone, shaly, hard, dark gray	-3,720	11
Limestone as above with white, tan and translucent anhydrite	-3,740	20
Limestone and anhydrite as above, plus some tan, dolomitic limestone	-3,772	32
Limestone, shaly, slightly dolomitic, brownish gray, pyritic	-3,807	35
Limestone, dolomitic, brownish gray, pyritic	-3,874	67
Limestone, shaly, slightly dolomitic, brownish gray, pyritic; some shale near base	-3,910	36
Limestone, dolomitic, brownish gray, pyritic; some anhydrite; contains ostracodes and miliolids	-3,985	75
Limestone as above, including gray shaly limestone and grayish black shale	-4,035	50
Limestone, dolomitic, brown to tannish gray; some anhydrite; contains ostracodes and miliolids	-4,050	15
Limestone, shaly, slightly dolomitic, brown and dark gray	-4,075	25
Limestone, dolomitic, brown and gray	-4,095	20
Limestone as above, plus gray to black shale	-4,122	27
Limestone, shaly, gray	-4,177	55
Limestone, dolomitic, tannish gray, and anhydrite	-4,200	23
Total thickness		660

Correlation.—The middle Albian age of the Edwards limestone in the subsurface must be determined by stratigraphic position, as its microfossils have not been studied. Its top apparently represents the same time plane as the top of the Goodland limestone of East Texas. The Goodland limestone cropping out northeast of Idabel, in southeastern Oklahoma, is about 12 feet thick, contains many rudistids in its upper 5 feet, and is lithologically more like the Edwards than like the Comanche Peak limestone. In the subsurface, separation of the Goodland from the Edwards on either a lithologic or geographic basis seems impossible. A specimen of *Oxytropidoceras* similar to *O. acutocarinatum* (Shumard) was cored at the depth of 6,365 feet in the upper 10 feet of the Goodland limestone penetrated by the Shell Oil Company's M. C. Sheppard well No. 1, located in the Manziel field, Wood County, Texas. Some cores of the Walnut clay contain an abundance of *Gryphaea mucronata* Gabb, which has been commonly but erroneously called *G. marcoui* Hill and Vaughan. Well preserved specimens of this species have been obtained at depths of 6,362 to 6,382 feet from the Magnolia

Petroleum Company's I. E. Robinson well No. 1 in the Coke field, Wood County, and at the depth of 6,290 feet in the Delta Drilling Company's Goldsmith-Blalock Unit No. 1 well in the Quitman field, Wood County.

The Edwards limestone is recognized in the Burro Mountains of northern Coahuila, but elsewhere in north-central Mexico it is included in the rudistid-bearing Aurora limestone.[52]

KIAMICHI FORMATION

Distribution and thickness.—The Kiamichi formation in the surbsurface of East Texas thins southward on the north flank of the San Marcos arch and disappears in Lee County, south of the town of Tanglewood. The formation reappears rather abruptly on the south flank of the San Marcos arch, as shown by its absence in the Amerada's Halff and Oppenheimer No. 2 in southwestern Frio County, and its thickness of 120 feet about 15 miles southwest in the Bay Oil Company's National Bank of Commerce No. 1. It is well developed in the subsurface of Maverick, Dimmit, and Zavala counties, where its known thickness ranges from 120 to 553 feet. It pinches out northward in Uvalde, Kinney, and Valverde counties and has not been identified on the outcrop in South Texas. Thus it is absent on the outcrop near Uvalde but is 363 feet thick in the Southern Crude Oil Company's Washer No. 1, about 12 miles south of Uvalde. It is 410 feet thick in the Pure Oil Company's Smyth No. 1, about 21 miles west-southwest of Uvalde. It is absent in the subsurface near Brackettville in central Kinney County but is 250 feet thick in the Magnolia Petroleum Company's Wardlaw No. 1, about 18 miles west of Brackettville. It is present in the southern tip of Valverde County but absent a few miles updip. Evidently the northern limit of the Kiamichi formation in South Texas extends northwest through the southwest corner of Frio County to a few miles south of Uvalde. It then curves west northwest through the southwest corner of Uvalde County, the southern part of Kinney County just south of Brackettville, and the southernmost few miles of Valverde County.

In northern Coahuila the Kiamichi formation is reported to be 80 feet thick in the American Smelting and Refining Company's Las Uvas No. 1, about 44 miles S. 28° W. of Eagle Pass, and 50 feet thick 18 miles farther southwest in the Ohio Oil Company's Cloete No. 1. Dark gray limestone and shale associated with gypsum and occupying the same stratigraphic position as the Kiamichi formation is reported[53] to be very well developed in the plain between the Burro Mountains and Del Rio, Texas, but is absent along the north front of the Burro Mountains. A thin unit of shale, marl, and thin-bedded limestone containing fossils characteristic of the Kiamichi formation has been identified as far west

[52] Imlay, *op. cit.* (1944), p. 1093.

[53] Personal communication from F. M. Getzendaner.

as eastern Chihuahua[54] and as far south as the Sierra de Lampazos, Nuevo León.[55]

Stratigraphic and lithologic features.—The Kiamichi formation in South Texas consists of hard, dense, calcareous, brownish black to black shale and shaly limestone interbedded with considerable anhydrite and locally rock salt. The shale has a massive texture and might more properly be called a highly calcareous claystone. Most of the limestone is shaly and dense, but some is granular, or oölitic, or dolomitic. Most of the anhydrite is dense and gray, white, or tan, but some is sugary. It occurs as thin seams interbedded with the shale and limestone and, also, in thick beds. Chert in large, angular pieces was cored in the upper 5 feet of the formation in Adams and Lyles' Mathews No. 1, Zavala County. Traces of chert were noted in cuttings about 85 feet below the top of the formation in the Humble Oil and Refining Company's Denton Estate No. 1, Dimmit County. Clear, crystalline rock salt was first encountered in the Rycade Oil Corporation's Chittim No. 2, Maverick County, at depths of 3,675 to 3,698 feet, or from 75 to 98 feet below the top of the formation.[56] Rock salt was later encountered in the Wellington Oil Company's Chittim No. 1-A and cored from depths of 3,843 to 3,884 feet, or from 58 to 99 feet below the top of the formation. Fossils appear to be uncommon, but miliolids and oyster fragments have been noted in some beds in the lower part of the formation.

In the subsurface of South Texas the lower boundary of the Kiamichi formation is fairly sharp in most sections but apparently conformable. However, a transitional zone between the Kiamichi and Edwards apparently is present in the deeper part of the Rio Grande embayment as indicated by the section in the Humble Oil and Refining Company's Denton Estate No. 1, Dimmit County, where stringers of miliolid-bearing limestone occur in the lower part of the Kiamichi. The upper boundary of the Kiamichi is gradational into the overlying Georgetown limestone and is difficult to select. However, near its northern boundary the Kiamichi must be overlain disconformably by the Georgetown, as indicated by the rapid pinch-out of the Kiamichi and by the overlap of the Georgetown onto the Edwards limestone. Apparently erosion of the Kiamichi occurred during Duck Creek time, because in the area of the San Marcos arch between San Marcos and New Braunfels, beds of Fort Worth age rest directly on the highly eroded surface of the Edwards limestone. Uplift and erosion of at least part of the Central Mineral Region during Duck Creek time may seem contradictory to Scott's observations,[57] based on studies of ammonites, that the

[54] Emil Böse, "Monografía geológica y paleontológica del Cerro de Muleros cerca de Ciudad Juárez y descripción de la fauna cretácea de la Encantada, Placer de Guadalupe, Estado de Chihuahua," *Bol. Inst. Geol. México*, Núm. 25 (1910), pp. 52, 53.

[55] Emil Böse and O. A. Cavins, "The Cretaceous and Tertiary of Southern Texas and Northern Mexico," *Univ. Texas Bull. 2748* (1927), pp. 23, 24.

[56] F. M. Getzendaner, "Geologic Section of Rio Grande Embayment, Texas, and Implied History," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 11 (1930), pp. 1426, 1427.

[57] Gayle Scott, "Paleoecological Factors Controlling the Distribution and Mode of Life of Cretaceous Ammonoids in the Texas Area," *Jour. Paleon.*, Vol. 14 (1490b), pp. 311, 317, 322.

lower part of the Duck Creek limestone may have been deposited at depths of 80 to 100 fathoms, and the marly upper part of the formation at depths of 20 to 80 fathoms. They seem even more contradictory to an observation, based on studies of *Foraminifera*,[58] "that the lower part of the Duck Creek was deposited in water 100–300 fathoms deep." However, partial reconciliation of these observations concerning depth of water with the evident facts of uplift and erosion in the San Marcos arch area may be made by considering (1) that uplift of landmasses is commonly accompanied by depression of adjoining basins, (2) that the depth of the Duck Creek sea may not have been as great as indicated by paleoecological studies, (3) that erosion occurred during only part of Duck Creek time, and (4) the statement by Scott[59] that in the Fort Worth area the "lower strata [of the Duck Creek] seem to have been trenched by ravines before the succeeding strata were deposited."

In the subsurface of East Texas, by comparison, the lower boundary of the Kiamichi formation is very sharp, and the upper boundary is less gradational than in South Texas. However, there is disagreement as to whether a thin unit of interbedded dark shale, marl, and limestone should be included in the Kiamichi or the Duck Creek formation.[60] On the outcrop in north-central Texas some rounded pebbles and grit occur at the Kiamichi-Duck Creek contact in a road cut in the western part of the City of Fort Worth.[61] Also, a large pebble was found at the same contact at Denison Dam on the Red River.[62] The presence of these pebbles might be interpreted as indicating a minor disconformity, although Lozo[63] has shown that many macrofossils and microfossils overlap the Kiamichi-Duck Creek boundary, and he believes that deposition was continuous.

Several of the best known sections of the Kiamichi formation in South Texas follow.

KIAMICHI FORMATION IN ADAMS AND LYLES-MATHEWS NO. 1, ZAVALA COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Limestone, extremely hard, dense, black; some thin beds of white anhydrite and large pieces of angular chert in core	3,935–3,940	5
Limestone and anhydrite as above, without chert fragments	–3,995	55
Limestone, dolomitic, granular, dark brown	–4,013	18
Limestone, dense, brown; contains streaks of anhydrite; a little brown, granular dolomitic limestone	–4,039	26
Limestone and shale, dark gray to black; some anhydrite	–4,072	33
Limestone, dense, brownish gray to black; contains a little anhydrite; some miliolids present	–4,200	128

[58] F. E. Lozo, Jr., "Bearing of Foraminifera and Ostracoda on Lower Cretaceous Fredericksburg-Washita Boundary of North Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27 (1943), p. 1076.

[59] Gayle Scott, "The Cretaceous of Texas," *XVI International Geol. Congress Guidebook 6* (1933), p. 53.

[60] T. L. Bailey, F. G. Evans, and W. S. Adkins, "Revision of Stratigraphy of Part of Cretaceous in Tyler Basin, Northeast Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29 (1945), pp. 172, 173.

[61] Adkins, *op. cit.*, p. 349.

[62] F. E. Lozo, Jr., "Bearing of Foraminifera and Ostracoda on Lower Cretaceous Fredericksburg-Washita Boundary of North Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27 (1943), p. 1063.

[63] *Op. cit.*, pp. 1063, 1070–75, 1079.

	Depth in Feet	Thickness in Feet
Limestone, granular, black and silvery black	−4,247	47
Limestone, hard, dense, dark brown; a few shell fragments	−4,275	28
Total thickness		340

Kiamichi Formation in Wellington Oil Company's Chittim No. 1-A, Maverick County, Texas

	Depth in Feet	Thickness in Feet
Shale, fissile, calcareous, shiny dark gray, fossiliferous; some hard, dense, brownish black, calcitic limestone; some gray anhydrite and clear rock salt cored at depth of 3,784 to 3,785 feet	3,785–3,800	15
Limestone, very hard, dark brown to black, finely crystalline; contains calcite veinlets	−3,809	9
Limestone as above, interbedded with considerable gray to white, granular anhydrite	−3,833	24
Anhydrite, dense, white and tan	−3,843	10
Salt, clear, crystalline (cored)	−3,884	41
Claystone, massive, calcareous, hard, dense, brownish black to black, containing many layers of white to brown, dense to granular anhydrite	−3,919	35
Claystone and limestone, hard, dense, brownish black to black	−3,992	73
Claystone and limestone as above, interbedded with much dense, white anhydrite	−4,067	75
Limestone, hard, dense, black; contains shell fragments; overlies yellowish gray Edwards limestone that contains miliolids	−4,075	8
Total thickness		290

Kiamichi Formation in Humble Oil and Refining Company's Denton Estate No. 1, Dimmit County, Texas

	Depth in Feet	Thickness in Feet
Shale, brittle, dark gray, fossiliferous; some brown to black limestone; traces of chert and anhydrite	7,177–7,312	135
Anhydrite, dense, white to gray; contains seams of calcareous, black shale and shaly limestone	−7,350	38
Shale and shaly limestone, dark brown to black, pyritic, locally oölitic; traces of anhydrite	−7,420	70
Limestone, shaly and calcareous shale, hard, dense, black	−7,514	94
Limestone, hard, dense, black; some black shale; a little anhydrite	−7,584	70
Anhydrite, white and gray; contains streaks of hard, dense, black, calcareous shale	−7,620	36
Shale, hard, calcareous, black; a few thin seams of anhydrite	−7,635	15
Anhydrite, dense, gray and white; contains seams of black shale	−7,646	11
Shale, dense, calcareous, black; some anhydrite	−7,651	5
Anhydrite with irregular areas and seams of black, calcareous shale	−7,667	16
Shale, black, calcareous; contains oyster fragments; much anhydrite	−7,673	6
Anhydrite and thin lenses of calcareous, black shale	−7,677	4
Shale, black, calcareous, and much anhydrite; contains oyster fragments	−7,682	5
Anhydrite and thin seams of calcareous, black shale	−7,687	5
Shale, black, calcareous; some oyster fragments	−7,705	20
Limestone, hard, dense, dark brown and anhydrite	−7,715	10
Limestone, dark brown to black, and calcareous, black shale; contains oyster fragments; overlies dark brown, miliolid-bearing limestone assigned to Edwards limestone	−7,730	15
Total thickness		553

Correlation.—In South Texas, the beds herein assigned to the Kiamichi formation have been known informally as the McKnight formation, after a section in the Texas and Maryland's S. E. McKnight well No. 1, located about 4½ miles

southwest of Carrizo Springs, Dimmit County, but to the writer there seems little doubt that they are equivalent to the Kiamichi formation of East Texas, and are not sufficiently different to justify a new name. The presence of the Kiamichi formation in South Texas is to be expected, as similar shale and limestone of that age are very widespread in northern Mexico as well as far to the north in the Western Interior region of the United States.

The Kiamichi formation of East Texas consists mainly of black, satiny, thinly laminated, splintery shale but includes many beds of *Gryphaea* shells, especially in its upper part, and becomes more and more calcareous eastward and southeastward. It differs from the Kiamichi formation of South Texas by being thinner, shalier, more fossiliferous, and by lacking anhydrite and salt. However, the resemblances of the shaly beds in the two areas are striking, particularly if comparisons are made with the more calcareous sections of the Kiamichi in the southeastern part of the East Texas basin.

Determination of the age of the Kiamichi formation as late middle Albian is based on studies of the ammonites found in surface outcrops and has been adequately discussed by Adkins[64] and Scott.[65]

GEORGETOWN LIMESTONE

Distribution and thickness.—The Georgetown limestone is present throughout the subsurface of South Texas, although in places on the San Marcos arch it is less than 30 feet thick, and in some wells is absent, owing to faulting. In the subsurface of East Texas it thickens basinward from about 220 to 720 feet. Outcropping Georgetown limestone, or its equivalents, is shown by Cuyler[66] to thin southward from a thickness of 375 feet in Cooke, or Grayson County, to 80 feet in Travis County. Along the western side of the East Texas basin the subsurface Georgetown limestone thins southward from a thickness of about 517 feet in Hunt County to 260 feet in Robertson County. Southward from Robertson County the subsurface Georgetown limestone thins more rapidly, and, on the crest of the San Marcos arch in Caldwell, Guadalupe, and Bexar counties, its recorded thickness ranges from 46 to 27 feet. Part of this thinning is depositional but part is a result or overlap of successively younger beds of the Georgetown on the Edwards limestone toward the crest of the arch, as may be demonstrated by comparisons of electric legs southward from Burleson County. The reality of the overlap may be seen on the outcrop between San Marcos and New Braunfels, where F. L. Whitney[67] has demonstrated that the Fort Worth, or even a younger

[64] *Op. cit.*, pp. 327, 359.

[65] Gayle Scott, "Ammonites of the Genus *Dipoloceras*, and a New *Hamites* from the Texas Cretaceous," *Jour. Paleon.*, Vol. 2 (1928), pp. 108–18.

[66] R. H. Cuyler, "Georgetown Formation of Central Texas and Its Northern Texas Equivalents," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), pp. 1291–99.

[67] Adkins, *op. cit.*, p. 360.
L. W. Stephenson, P. B. King, W. H. Monroe, and R. W. Imlay, "Correlation of the Outcropping Cretaceous Formations of the Atlantic and Gulf Coastal Plain and Trans-Pecos Texas," *Bull. Geol. Soc. America*, Vol. 53 (1942), p. 443.

formation of the Washita group, rests directly on the highly eroded surface of the Edwards limestone. In South Texas west of Bexar County the Georgetown limestoee ranges in thickness from 30 to 50 feet on the outcrop in Uvalde and Medina counties to more than 500 feet in the subsurface in Kinney, Maverick, Dimmit, and Zavala counties. A maximum thickness of 720 feet is recorded in the Wellington Oil Company's Chittim well No. 1-A, Maverick County. These thicknesses are comparable with the 595 feet exposed in the northern part of the Burro Mountains, Coahuila, near El Cedrito Ranch. West of Uvalde County the outcropping Georgetown limestone changes into a thicker rudistid facies, of which about 180 feet are exposed near the mouth of Devils River in Valverde County.

Stratigraphic and lithologic features.—The Georgetown limestone of the subsurface of South Texas consists of units of soft, chalky, slightly porous, white to brown limestone, marl, and shale, alternating with units of hard, dense, gray to brownish gray limestone. Some of the harder beds are mottled brown and gray. In the thick sections on the Chittim anticline in Maverick County, one prominent unit of brown limestone is encountered about 110 feet below the top of the Georgetown limestone, and another brown unit about 500 feet below the top. Similar conspicuous units have not been noted elsewhere. In most sections the lower one-half to one-third of the Georgetown limestone is harder and more calcareous than the overlying beds. Perhaps this lower, harder part corresponds with the beds of Duck Creek and Fort Worth age on the outcrop, but detailed lithologic and faunal studies necessary to demonstrate such correlations have not been made. Many beds contain tiny, round bodies, or microspherules, of calcite that in sample descriptions are generally recorded as spherical bodies, oölites, or coccoliths. These are particularly common in the Washita group and sparse in the Fredericksburg group. Miliolids and rudistids are generally absent, except where the Georgetown limestone passes into a rudistid facies west of Uvalde County. In general, the Georgetown limestone contains an abundance of microfossils and shelly material. Pyrite is fairly common, particularly in the harder beds. Adkins'[68] summary of the microscopic features of the outcropping Georgetown limestone applies very well to that formation in the subsurface.

In the subsurface of South Texas the Georgetown limestone grades upward with perfect transition into the Grayson shale within an interval of 10 to 20 feet. Generally the transition beds are placed in the Georgetown. This relationship agrees with Adkins'[69] observation that "Thoughtout Texas the Grayson is underlain concordantly and apparently conformably by the Main Street formation or member of the Georgetown limestone." However, Curry[70] notes that in the western part of the Edwards Plateau the base of the Georgetown limestone is dif-

[68] *Op. cit.*, p. 365.

[69] *Opl cit.*, pp. 387, 388.

[70] W. H. Curry, Jr., "Fredericksburg-Washita (Edwards-Georgetown) Contact in Edwards Plateau Region of Texas," *Bull. Amer. Assoc. Petrol. Geol.* (Vol. 18, 1934), p. 1700.

ferentiated from the Edwards limestone by "a horizon of *Gryphaea*, the base of which is from 130 to 220 feet below the Del Rio clay. The variation in the thickness is due to an unconformity at the top of the Georgetown." Likewise, Getzendaner[71] points out that over much of the Del Rio area "the top of the Georgetown has been removed by erosion." Suggestive of an unconformity is the observation by Adkins[72] that from Del Rio the Grayson shale

> outcrops in a straight band running a little west of south for 45 miles to Tinaja Azul, about 6 miles south-southwest of Remolino, Coahuila, where it disappears. Over this area it gradually thins southward, until the Georgetown and Buda come to lie in concordant contact. The upper zone of the Grayson, marked by an abundance of *Exogyra cartiledgei*, as seen near El Sauz, Goodwin Ranch, and Remolino, persists, and the basal zones drop out, whether by overlap or by change of facies is unknown.

Some of the better known sections of deep wells in South Texas are described in the following pages.

GEORGETOWN LIMESTONE IN BAY OIL CORPORATION'S NATIONAL BANK OF COMMERCE NO. 1, ZAVALA COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Limestone, soft, dense, brownish gray, fossiliferous	6,721–6,730	9
Limestone, hard, gray to tannish gray, pyritic; some chalky, white, and soft	–6,740	10
Limestone, soft, chalky, white, and some hard gray to tannish gray limestone	–6,830	90
Limestone, hard, gray, with a few microspherules, pyritic; some soft, chalky, white limestone and some brownish gray limestone	–6,860	30
Limestone, hard, dense, gray to brown; much mottled brown to white; fossiliferous	–6,868	8
Limestone, soft, chalky, white	–6,880	12
Total thickness		159

GEORGETOWN LIMESTONE IN RYCADE OIL CORPORATION'S SULLIVAN NO. 5, MAVERICK COUNTY, TEXAS

	Depth in Feet	*Thickness in Feet*
Limestone, medium hard, dense, light gray to brownish gray; contains many tiny spherical bodies or oölites, pyritic	2,607–2,675	68
Limestone, medium hard, dense, white	–2,700	25
Limestone, soft, slightly porous, brown to cream-colored, with veinlets of calcite and pyrite; a little hard, gray limestone	–2,780	80
Limestone, hard, gray, dense, pyritic, with many microspherules; a little grayish black shale	–2,850	70
Limestone, hard, pale brownish gray, finely crystalline; a little black shale	–2,920	70
Limestone, hard, gray, finely crystalline; some calcareous, brown shale	–2,935	15
Limestone as above, with calcareous black shale and much pyrite	–3,015	80
Limestone and shale as above, with many microspherules	–3,070	55
Limestone, hard, gray, and calcareous, black shale	–3,095	25
Limestone, hard, mottled brown and gray; some granular brown limestone and calcareous, black shale	–3,130	35
Limestone, hard, gray, dense; many microspherules	–3,170	40
Limestone, light brownish gray	–3,192	22
Limestone, gray, dense; many microspherules	–3,215	23
Limestone, brown and gray mottled; many microspherules	–3,235	20
Limestone, hard, dense, gray	–3,310	75
Total thickness		703

[71] F. M. Getzendaner, "Problem of Pre-Trinity Deposits in South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27 (1943), p. 1240.

[72] *Op. cit.*, p. 391.

Georgetown Limestone in Wellington Oil Company's Chittim No. 1-A, Maverick County, Texas

	Depth in Feet	Thickness in Feet
Limestone, hard, dense, dark gray, with many microspherules and some pyrite streaks, locally lignitic; some beds shaly; a few fossils cored....	3,065–3,100	35
Limestone, hard, dense, tannish gray, oölitic, fossiliferous, slightly pyritic..	–3,109	9
Limestone, as above, plus considerable dark gray to brown, brittle, fossiliferous shale	–3,199	90
Shale, mostly calcareous, dark gray, micaceous, brittle; some dark brown and finely laminated; much dense tannish gray limestone containing micropherules of calcite	–3,259	60
Limestone, dense, tannish gray, with many microspherules; some calcareous, brittle, brown and gray, fossiliferous shale; very fossiliferous	–3,728	469
Limestone, hard, dense, light gray, fossiliferous, with many microspherules; slightly pyritic	–3,785	57
Total thickness		720

Georgetown Limestone in Adams and Lyles' Mathews No. 1, Zavala County, Texas

	Depth in Feet	Thickness in Feet
Limestone, hard, gray; contains microspherules, and a few shell fragments..	3,400–3,420	20
Limestone, hard, white; contains microspherules	–3,615	195
Limestone, light to dark gray; some shell fragments and microspherules...	–3,650	35
Limestone, gray; contains microspherules of calcite; fossiliferous	–3,670	20
Limestone, white and gray, fossiliferous	–2,684	14
Limestone, hard, cream to tan, fossiliferous, slightly porous, slightly glauconitic	–3,730	46
Limestone, fairly soft, light gray, fossiliferous	–3,775	45
Limestone, soft, light creamy tan, slightly porous	–3,884	109
Limestone, soft, white to cream, fossiliferous	–3,934	50
Total thickness		534

Georgetown Limestone in Amerada Petroleum Corporation's Halff and Oppenheimer No. 8, Frio County, Texas

	Depth in Feet	Thickness in Feet
Limestone, gray, finely crystalline; contains some very small, round microspherules; traces of hard white, or tan limestone	6,100–6,120	20
Limestone, gray, tan, and brown, dense to finely crystalline; some round microspherules	–6,170	50
Limestone, mostly hard, dense, light gray to tan; some brown and finely crystalline; some soft and white; trace of pyrite	–6,210	40
Total thickness		110

The following section in the Burro Mountains of northern Coahuila is included for comparison with the Texas sections. It was measured by F. M. Getzendaner in 1941 and is published with his permission.

Georgetown Limestone Cropping Out at El Cedrito Ranch in Northern Part of Burro Mountains about 65 Miles West-Southwest of Del Rio, Texas

	Thickness in Feet
Limestone, mostly fairly thick-bedded and hard; basal 10 to 30 feet brown and flaggy; upper part commonly contains a bed of rudistids and a bed consisting mainly of large Gryphaeas and Pectens	65
Conglomerate of well rounded limestone pieces as much as 3 inches in diameter, very poorly cemented; contains many rudistid colonies and very large *Turritella*-like forms.	50
Limestone, thin-bedded, and marl, white to gray; rather typical Georgetown but contains two rudistid-bearing beds and much chert	480
Total thickness	595

Correlation.—The Georgetown limestone of South Texas passes west of Uvalde into the upper part of the rudistid-bearing Devils River limestone,[73] which crops out in the area of the Big Bend and in the lower Pecos Valley. Similarly, in northern Coahuila, the Georgetown limestone exposed in the Burro Mountains passes westward in northwestern Coahuila into the upper part of the Devils River limestone. Other Mexican equivalents have been discussed sufficiently elsewhere.[74]

The Georgetown limestone appears to represent the same time-interval throughout its extent, except where the Kiamichi formation is missing, and to be equivalent to the upper Albian of the European sequence. Adkins[75] has noted that "the tops of the ranges of the ammonite genera *Dipoloceras* and *Oxytropidoceras*, and the bottom of the ranges of *Elobiceras* and *Pervinquieria*, mark the base of the upper Albian, and approximately coincide with the Kiamichi-Duck Creek boundary." Böse[76] and Adkins[77] have presented considerable evidence that the Georgetown is upper Albian in age and that the overlying Grayson and Buda formations are lower Cenomanian in age. Their conclusions have been accepted by most Mesozoic paleontologists.

The upper Albian age of the Georgetown limestone is shown by the presence of *Pervinquieria*, or closely related genera, in beds from the Duck Creek limestone to the Main Street limestone.[78] The Cenomanian age of the Grayson (Del Rio) shale is shown[79] (1) by the occurrence of *Engonoceras* and evolute *Scaphites* similar to forms in the Cenomanian of Africa, (2) by the absence of distinctly upper Albian ammonites, and (3) by the presence of *Cunningtoniceras*, a Cenomanian ammonite genus, in the transitional beds at the base of the Grayson shale.[80] The Cenomanian age of the Buda limestone is shown by the presence of the ammonites *Mantelliceras*, *Sharpeiceras*, and *Euhystrichoceras*. *Budaiceras*, until recently known only from the Buda limestone, has now been recorded from Madagascar, where it is associated with *Elobiceras* above upper Albian beds containing *Pervinquieria* and below lower Cenomanian beds containing *Mantelliceras*.[81]

[73] Adkins, *op. cit.*, pp. 325, 361.
A. N. Sayre and R. R. Bennett, "Recharge, Movement, and Discharge in the Edwards Limestone Reservoir, Texas," *Amer. Geophysical Union Trans. of 1942*, p. 20.

[74] Imlay, *op. cit.* (1944), pp. 1095–97.

[75] *Op. cit.*, p. 327.

[76] Emil Böse, "Cretaceous Ammonites from Texas and Northern Mexico," *Univ. Texas Bull. 2748* (1927), pp. 146–161.

[77] *Op. cit.*, pp. 363, 364, 385, 386, 400.

[78] Adkins, *op. cit.*, pp. 364, 385, 386.

[79] Böse, *op. cit.*, pp. 154–161.

[80] Adkins, *op. cit.*, p. 385.
Böse, *op. cit.*, pp. 152–54.

[81] Besairie, Henri, "Recherches géologiques à Madagascar. Première suite; La géologie du nord-ouest," *Acad. Malgache Mém.*, fasc. 21 (1936), pp. 89, 199, 200, Pl. 21, Figs. 14–16.

An upper Albian age for the Grayson shale and the Buda limestone has been supported by Scott[82] on the basis that the upper part of the Grayson shale contains *Stoliczkaia* aff. *S. dispar* (D'Orbigny), and that the Buda limestone is the southern Texas equivalent of the upper part of the Grayson shale. However, recent studies[83] have shown definitely that the Buda limestone overlies the Grayson shale normally in the subsurface of the East Texas basin as far north as central Red River and Lamar counties, that isolated erosional remnants of the Buda limestone crop out as far north as Denton County, and that the absence of the Buda limestone in parts of northeastern Texas is a result of erosion prior to the deposition of the Gulf series. This stratigraphic information, plus the presence of the Cenomanian ammonite genera already mentioned and the absence of distinctive Albian ammonites, shows that the Buda limestone is younger than the Grayson shale and of undoubted Cenomanian age. Some support for Scott's assignment of the Grayson shale to the upper Albian is derived from the facts that the Grayson does contain *Stoliczkaia* comparable with *S. dispar* (D'Orbigny) and that the ammonites of Cenomanian affinities are inadequately illustrated. The association of *Stoliczkaia* with *Mantelliceras* in Switzerland[84] might not be accepted by Scott as evidence that *Stoliczkaia* ranges up into the Cenomanian, but rather that *Mantelliceras* existed as early as the Albian. The writer considers that the evidence that has been presented for the Cenomanian age of the Grayson shale is much stronger than that for its Albian age, but would welcome any additional evidence that might result from careful stratigraphic and faunal studies of the Grayson shale and adjoining formations.

The boundary between the Comanche and Gulf series need not correspond with the boundary between the Lower and Upper Cretaceous, as the former marks the position of a pronounced unconformity, whereas the latter is based mainly on historical precedent and practicality. In discussing the boundary between the Lower and Upper Cretaceous in Europe, Spath[85] notes that various geologists have chosen different boundaries and that the matter was finally settled by a decision of the International Geological Congress at Zürich in 1885 that placed the Gault (middle and upper Albian) in the Lower Cretaceous.

[82] Gayle Scott, "Études stratigraphiques et paléontologiques sur les terrains crétacés du Texas," *Thèse, Université de Grenoble* (1926a), pp. 85–90, 141.

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[83] Lloyd W. Stephenson, "Fossils from Limestone of Buda Age in Denton County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28 (1944), pp. 1538–41.

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[84] L. F. Spath, "Ammonoidea of the Gault," *Palaeontographical Soc.*, Pt. 8 (1931), p. 331.

[85] L. F. Spath, "On the Boundary between the Upper and Lower Cretaceous," *Geol. Magazine*, Vol. 78 (1941), pp. 309–15.

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RELATION OF RADIOACTIVITY, ORGANIC CONTENT, AND SEDIMENTATION[1]

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ABSTRACT

A comparison between the radioactivity and organic content of 510 samples of sedimentary rocks indicates a marked relation between certain types of organic content and radioactivity. Marine oil shales are associated with exceptionally high radioactivity, coals with abnormally low radioactivity, and other types of organic matter with intermediate radioactivities. An analysis of the material balance between sedimentary and igneous rocks indicates that the sediments should have about the same radioactivity as the igneous rocks from which they were derived; the averages of the writer's tests seem to confirm this conclusion if the igneous source of the sediments resembles a granite. An analysis of the data bearing on the radioactivity of deep-sea deposits and oil shales indicates no evidence of a general increase in radioactivity with slowness of deposition. The bearing of the new data on the origin of oil and of the helium in natural gas is discussed.

INTRODUCTION

In a recent paper the writer[3] gave a list of 510 determinations of the radioactivity of sedimentary rocks, described the relation between radioactivity and lithologic character, and cited some practical geophysical applications of the data. During this investigation, it became clear that certain types of organic matter were associated with abnormally high radioactivity, others with low or normal radioactivities, and that the results of the work were related to a number of problems of general geologic interest. The discussion of these has been reserved for the present paper. The work was done in 1941 to 1943 as part of a research program for Well Surveys, Inc.

RELATIONS BETWEEN RADIOACTIVITY AND ORGANIC CONTENT

During the study of radioactivity well logs, it speedily became apparent that marine bituminous shales are of extremely high radioactivity, as the writer[4] pointed out some time ago. On the other hand, it is certainly not true that the radioactivity increases with the organic content, for some organic materials, such as coal, are associated with very low radioactivities, and others with radioactivities which are about normal. It is therefore of obvious importance to determine the nature of the organic content, and accordingly each sample was tested by a method previously described by the writer,[5] which involves heating the crushed rock in a glass tube closed at one end. Any organic matter present will

[1] Manuscript received, May 22, 1945.

[2] Stanolind Oil and Gas Company.

[3] W. L. Russell, "The Total Gamma Ray Activity of Sedimentary Rocks as Indicated by Geiger Counter Determinations," *Geophysics*, Vol. 9, No. 2 (April, 1944), pp. 180–216.

[4] William L. Russell, "Well Logging by Radioactivity," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 9 (September, 1941), pp. 1768–88.

[5] *Idem*, "Some Characteristics of Organic Content of Rocks," *ibid.*, Vol. 18, No. 9 (September, 1934), pp. 1103–25.

be distilled, generally destructively, and the various distillates, sublimates, fumes, and odors produced serve to classify roughly the different types of organic matter.

The apparatus, methods, and accuracy of the results are described in the previous paper. The results of the tests are given in Table I, in which column 1 gives the serial number of the determination, and column 2 the radioactivity, expressed in units of gamma-ray intensity. One unit of gamma-ray intensity would be produced by a rock containing 1×10^{-12} gram of radium per gram of rock, in equilibrium with other members of the uranium-radium series. Since potassium and members of the thorium series also contribute to the results, the figures are generally much higher than the more familiar values which indicate solely the radium concentration. Columns 3 to 11 show the indications of organic content found, and columns 12 to 20 the lithological characteristics. The location and age of each sample together with the geologic formation which it represents may be obtained by referring to Table III of the previous paper,[6] since the serial numbers are the same.

The indications of organic matter and their significance may be described as follows.

1. *Liquid oil* (Column 3, Table I).—Bituminous or oil shales yield on distillation liquid oil which condenses on the walls of the tube in drops. The oil is produced by the destructive distillation of the kerogen or other solid organic matter present; generally, little or no liquid oil is present in the shales before heating. Of course, many sandstones, limestones, and dolomites contain liquid oil or the residues formed by the drying or oxidation of liquid oil, and these also yield on distillation liquid oil, which appears in columns 3 and 4, Table I, in the same manner as the oil produced by the distillation of the oil shales. This free oil may generally be differentiated from the bituminous matter by visual examination. The fourth column of Table I indicates odor of oil; and it should be noted that in many cases oil which can not be seen can be detected by its odor. The symbol "xxx," indicating maximum content of liquid oil, corresponds very roughly with a yield of 10 gallons of oil per ton of shale.

2. *Visible fumes* (Column 5, Table I).—While most oily, tarry, coaly, and bituminous types of organic matter yield visible fumes or vapors when distilled, this symbol is always indicated only when it is not accompanied by oil, tar, or one of the characteristic organic odors. Its importance in such cases is that it indicates the presence of a different type of organic matter which would not otherwise be recognized.

3. *Tarry odor* (Column 6, Table I).—This odor is produced by coal and by carbonaceous or coaly matter. It may be accompanied by a dark, tarry distillate or sublimate.

4. *Odor of ammonia* (Column 7).—This odor, ordinarily found only in shales, presumably indicates a different type of organic content.

[6] W. L. Russell (April, 1944), Table III.

TABLE I

List of Determinations of Radioactivity and Organic Content, with a Summary of Salient Lithologic Characteristics

The intensity of a given characteristic is proportional to the number of x's in the appropriate space. Thus, no x indicates that the characteristic is not found, and xxx indicates that it is prominent. In the column headed "shade" the meaning is as follows.

x	Grayish white to white
xx	Medium to light gray
xxx	Dark gray
xxxx	Grayish black
xxxxx	Black

The symbol * following the serial number denotes samples collected from outcrops.

1. Serial Number	2. Radioactivity	3. Liquid Oil	4. Odor of Oil	5. Visible Fumes	6. Tarry Odor	7. Odor of Ammonia	8. SO₃ Odor	9. Sublimate	10. Odor of Scorching	11. Oil Odor when Broken	12. Other Odors	13. Shale and Clay	14. Lime or Dolomite	15. Sand	16. Silt	17. Chalk	18. Chert	19. Shade	20. Red	21. Green	22. Coal
1	2.0												x	xxx	x			x			
2	7.1					x		xx				xxx			x			x			
3	8.4							xx				xxx						xxx			
4	3.7							xx					x	xxx	x			x			
5	10.5						x	xx				xxx			x			x			
6	4.1	miss	ing																		
7	10.1		xx			xx		xxx				xxx	x		x			xxx			
8	5.4		xx					xx				x	x	xxx	x			xxx			
9	17.0		xx					xxx				xxx						xxx			
10	19.5						xxx	xxx				xxx						xxx			
11	17.5						xxx	xxx				xxx						xxx			
12	17.3						xxx	xxx				xxx						xxx			
13	3.7	xx	xxx											xxx				x			
14	18.7							xxx				xxx			x			x			
15	2.3	xxx	xxx											xxx				xx			
16	8.7	xxx	xxx											xxx	x			x			
17	12.7						x	xxx						xxx	xx			x			
18	26.2						x	xxx				xxx						xxx			
19	4.9						x	x						xxx				x			
20	8.5		xxx					xxx				xxx	x					xxx			
21	5.5	xx	xxx											xxx				xx			
22	10.0		xx				xxx	xxx				xx		xxx				xxx			
23	4.0	xx	xxx											xxx				xx			
24	3.5	xx	xxx										x	xxx				xx			
25	7.5	xx	xxx										x	xxx				xx			
26	4.0		xxx									x	x	xxx				xx			
27	13.1	x	xxx				xxx	xxx				x		xxx	x			xxx			
28	8.7	xx	xxx					xxx				x	x	xxx	x			xxx			
29	23.1		xxx				xx	xxx				xxx		x	x			xxxx			
30	4.2						xxx	xxx						xxx				x			
31	6.2						xx	xx						xxx				x			
32	2.7						x	x						xxx				x			
33	6.7	x	xxx					x				x		xxx				x			
34	9.7						x	xx				x		xxx	x			x			
35	21.2		x				xxx	xxxx				xxx						xxx			
36	21.3		x					xxx				xxx			x			xxx			
37	5.8	xx	xxx					x						xxx				x			
38	8.0	xx	xxx					xxx				xxx	x	x				xxx			
39	15.4			xxx		xx		x			xxx	xxx						xxx			
40	23.6	xx	xxx	xxx			xx	xxx				xxx						xxxx			
41	16.7			xx				xxx			xx	xxx	x					xxx			
42	3.1										x			xxx				x			
43	17.4							xxx										xx		xx	
44	<2						xxx	xxx					xxx					x			
45	<2						xxx	xxx										x			
46	2.0							x										x			
47	59.6	xxx	xxx									xxx						xxxxx			
48	38.8	xxx	xxx									xxx						xxxxx			
49	14.9											xxx						xx			
50	<2																	xxxxx			xxx
51																					
52																					
53																					
54	7.6	xxx	xxx											xxx				xx		x	
55	9.1	xxx	xxx				xx							xxx	x			xx		xx	
56	6.5							xxx					xxx	x				x		xx	
57	6.5							xxx					xxx	x				x		xx	
58	6.5	xxx	xxx											xxx				xx			

TABLE 1—*Continued*

1. Serial Number	2. Radioactivity	3. Liquid Oil	4. Odor of Oil	5. Visible Fumes	6. Tarry Odor	7 Odor of Ammonia	8. SO_2 Odor	9. Sublimate	10. Odor of Scorching	11. Oil Odor when Broken	12. Other Odors	13. Shale and Clay	14. Lime or Dolomite	15. Sand	16. Silt	17. Chalk	18. Chert	19. Shade	20. Red	21. Green	22. Coal
59	11.5	xxx	xxx											xxx	xxx			xx		xx	
60	2.5	xxx	xxx										xxx					x			
61	3.7	xx	xxx										xxx					x			
62	4.5	Miss	ing										xxx					xxx			
63	3.5	xxx	xxx										xxx					xxx			
64	4.8		Miss	ing									xxx					x			
65	2.5	xxx	xx										xxx					xx			
66	<2	xx	x					xxx					xxx					x			
67	<2		?	xxx	xxx													xxxxx			xxx
68	<2			xxx	xxx													xxxxx			xxx
69	<2			xxx	xxx													xxxxx			xxx
70*	15.5				xxx		xxx	xxxx				xxx						xxx			
71*	6.5	xx		x								x	x		xxx			xxx			
72*	15.5					x						xx	xx					x			
73*	30.5	xxx	xxx	xxx								xxx						xxxx			
74*	9.5						xxx	xxxx			xxx	xxx	x					xxx			
75*	13.5							xx			xx							x			
76	<2		xx				xx						xxx					xx			
77	<2							xxx					xxx					x			
78	2.4	xx	xxx											xxx				x		xx	
79	<2	xx	xxx											xxx				x		xx	
80	<2	x	xx										xx	xxx				x			
81	<2	x	xx										xx	xxx				x			
82	<2	xxx	xxx											xxx				xx			
83	<2	xxx	xxx											xxx				xx			
84	<2	x	xxx										xxx	xx				x			
85	<2	xx	xxx											xxx				xx			
86	<2		xx					x					x	xxx				x			
87	<2	x	xx										x	xxx				x			
88	<2	xx	xxx										xx	xxx				xx			
89	<2	x	xx										xx	xxx				x			
90	<2	xx	xxx											xxx				xx			
91	<2		xx					xx					xx	xxx				x			
92	10.8		xx	xx			xx	xxx						xxx	x			xx	xx		
93	<2	x	xx					xxx					xxx					x			
94	2.0	xxx	xxx							xxx			xxx					xx			
95	2.0	xxx	xxx										x	xxx				x			
96	12.6						xx	xxx				xxx	x					xx		xx	
97	5.4	xxx	xxx											xxx	x			xx			
98	23.7			xxx			xxx	xxx				xxx						xxxx			
99	16.3							xx			xx	xxx		x	x			xxxx			
100	4.2							xxx						xxx				x			
101	<2							x			x	x	xxx					x			
102	3.6	x	xx						xx		x		xxx					x			
103	<2							xx					xxx					x			
104	6.0	xxx	xxx		xxx							xxx		xx				xxxxx			
105*	2.1																xxx	x			
106*	3.3																xxx	x			
107*	<2																xxx	x			
108*	<2																xxx	x			
109*	2.4								x								xxx	x			
110*	<2																xxx	x			
111*	13.2	xx	xxx									xxx						xxx		xx	
112	3.6	xxx	xxx											xxx				xx			
113	6.3	x	xxx				xx	xxx						xxx	x			xx		xx	
114	11.4							xxxx				xxx						xx	xx		
115	7.2							xxx										xx		xx	
116																					
117																					
118	<2		xx		xxx			xxx	xx				xxx	x				x			
119	13.2	x	xx	xxx								xxx		x				xxx			
120	8.1	xxx	xxx	xx								x		xxx				xx			
121	9.0	x	xx	xxx								x	x	xxx				xx			
122	18.3			xxx	xx	xx						xxx						xxxx			
123	6.3	xxx	xxx										x	xxx	x			xxx			
124	11.7			xxx							xx	xxxx						xxx			
125	6.0	xxx	xxx									x		xxx	x			xx			
126	14.4			xx			xx	xx				xxx			x			xxx			
127	4.5						x	x				x	x	xxx	x			xx			
128	9.9			xxx	xxx							xxx						xxxx			
129	3.6							x				x		xxx	x			xx			
130	12.6				xxx							xxx		x				xxx			
131	10.2					xx						xxx						xxx			
132	3.0						xxx	xx				x		xxx				x			
133	14.7			xxx	xxx							xxx						xxxx			
134	9.9			x	xx							xxx						xxxx			

TABLE I—*Continued*

1. Serial Number	2. Radioactivity	3. Liquid Oil	4. Odor of Oil	5. Visible Fumes	6. Tarry Odor	7. Oder of Ammonia	8. SO_2 Odor	9. Sublimate	10. Odor of Scorching	11. Oil Odor when Broken	12. Other Odors	13. Shale and Clay	14. Lime or Dolomite	15. Sand	16. Silt	17. Chalk	18. Chert	19. Shade	20. Red	21. Green	22. Coal
135	3.9	x	xx									x		xxx	x			xx			
136	5.1							xx				x		xxx	x			xx			
137	14.1				xx			xx				xxx			x			xxx			
138	3.3	xx	xxx											xxx	x			xx			
139	14.4			xx	xx			x				xxx		x				xxx			
140	6.3				xx			x			xx	x	x	xxx	x			xx			
141	12.3			xx	xx	xx		x				xxx			x			xxx			
142	10.2												x	xxx	x			xx			
143	13.3			xx	xxx	xx						xxx			x			xxxx			
144	6.0	x	xx									x	x	xxx				xxx			
145	13.5		x	x	xx	x						xxx			x			xxx			
146	4.8	xx	xxx	xx										xxx				xx			
147	<2	x		xx			xx							xxx				xx			
148	4.5		x			x		xx				x	x	xxx	x			x			
149	14.7		xx	xx	xxx			x				xxx		x				xxxx			
150	8.7			xx	xxx							x		xxx				x			
151	17.1			xxx	xxx							xxx						xxx			
152	4.2													xxx				x			
153	17.7			xxx	xxx	xx						xxx		xxx				xx			
154	13.8			xx			xx	xxx				xxx			x			xxx			
155	<2	xx	xxx											xxx				xx			
156	10.8			xx			xx					xxx						xxx			
157	15.6			xx		xx						xxx						xxxxx			
158	12.6			xx		xx						xxx						xxxxx			
159	12.1			xx		xx						xxx						xxxx			
160	12.9			xx		xx						xxx						xxxxx			
161	19.2			xx		x		xx				xxx						xxx			
162	19.8			xx				x				xxx						xxxxx			
163	19.2			xx		xx						xxx						xxxxx			
164	13.2			xxx			xxx	x				xxx		x				xxx			
165	15.5			xx	x	x		x				xxx		xxx				xxx			
166	8.3													xxx				x			
167	8.6							x				x		xxx				xxx			
168	5.4						x							xxx	x			x			
169	7.9						xx	x				x		xxx	x			x	x		
170	15.1					x	x	x				xxx			xxx			xxx			
171	4.7			xx			xxx	xxx						xxx				xx			
172	6.1			xx			xxx	xxx				x		xxx				x			
173	16.9			xx	xx	xx						xxx		x				xxxx			
174	<2	xx	xxx										x	xxx				x			
175	<2	x	xx	xxx																	
176	20.5	x		xxx				xxxx				xxx						xxxxx			
177	17.4	x		xxx				xxxx				xxx						xxxxx			
178	28.2			xxx	xx			xxxx			xx	xxx						xxxxx			
179	22.3	x	xxx	xxx	xx	xx		xxxx				xxx						xxxxx			
180	25.6	x	xxx	xxx	xx			xxxx				xxx						xxxxx			
181	18.8							xxxx				xxx						xxx			
182*	2.7																				
183*	4.2																				
184*	33.1	xxx	xxx	xxx								xxx						xxxxx			
185*	33.4	xxx	xxx	xxx								xxx						xxxxx			
186*	<2	xxx		xxx	xxx													xxxxx			xxx
187*	29.6						x	xxxx										x			
188*	15.5	xxx		xxx	xxx							xxx						xxxxx			
189*	<2	xxx	xxx	xxx													xxx	xxxx			
190*	43.9	xxx	xxx	xxx								xxx						xxxxx			
191	37.4	xxx	xxx	xxx								xxx						xxxxx			
192	7.2			xxx				xxxx			xx						xxx	x			
193	8.7	x	xxx	xx				xxx					x	xxx	x			xx			
194	5.6							xxxx					xxx					xx			
195	<2	x	xx					xx					xxx					x			
196	4.2							xx						xxx				x			
197	12.3					xxx		xx				x	xxx					xx			
198	6.1	x	xx										x	xxx	x			xx			
199	6.5					xxx		xxxx				x		xxx				xx		x	
200	3.5							xxx			xxx			xxx				x			
201	3.7					x		xxxx					x	xxx				x			
202	16.9					xx		xxxx				xxx						xxx			
203	24.9							xx			x	x	x		xxx			xxx			
204	22.4			xxx				xxxx			x	xxx						xxx			
205	6.5												xxx					xx			
206	20.6			xx		x		xxxx			xx	xxx	x					xxx			
207	19.2			xx	x		x	xxxx				xxx						xxxx			
208	2.5						x						xxx					x			
209	9.5	xx	xxx	xxx										xxx	x			x		x	
210	18.4			xx		xxx		xxx				xxx	x					xxx			

TABLE I—*Continued*

1. Serial Number	2. Radioactivity	3. Liquid Oil	4. Odor of Oil	5. Visible Fumes	6. Tarry Odor	7. Odor of Ammonia	8. SO_2 Odor	9. Sublimate	10. Odor of Scorching	11. Oil Odor when Broken	12. Other Odors	13. Shale and Clay	14. Lime or Dolomite	15. Sand	16. Silt	17. Chalk	18. Chert	19. Shade	20. Red	21. Green	22. Coal
211	<2							x	x				x	xxx				x			
212	12.8					xx		xxx				x	xxx					xxx		x	
213	17.3			xxx	xx			xxxx				xxx			x			xxx			
214	9.7			xxx	xx			xxxx							xxx			xxx			
215	7.9							xx	x				x	xxx				x			
216	<2								x				xxx					x			
217	7.6							x					xxx					xx			
218	9.7					xxx						xxx						xxx			
219	24.2			xx		xx		xxx				xxx						xxx		x	
220	2.5												xxx					x			
221	2.5												xxx					x			
222	<2						xxx	xxx						xxx				x			
223	<2	xx	xxx	xxx										xxx				xx			
224	18.0			xx		xx		xxx				xxx						xxx			
225	12.2					x		xxx				x			xxx			x			
226	16.2					xxx		xxx				xxx	x		x			x			
227	<2	xx	xxx											xxx				x			
228	<2	x	xx	xx								x		xxx	x			x			
229	8.6	x	xx	xx								x	x	xxx	x			xxx			
229A	<2								x				xxx					x			
230	5.8			xx				xxx			x		x	xx	xxx			x			
231	13.0			xx	x			xxx					xxx					xxx			
232	<2	xxx	xxx										x	xxx				x			
233	4.1			xxx	xx			xxx					x		xxx			x			
234	3.2	x	xx										x	xxx				x			
235	<2	xx	xxx										x	xxx				xx			
236	12.6					xx		xxx				xxx						x		xx	
237	5.4												xx	xxx				x			
238	8.3							xxx					xxx		x			x		xx	
239	17.6			xxx	xx			xxxx				xxx	x					xxx			
240	2.5	xxx	xxx	xxx									xxx					x			
241	12.6			xx		x		xxx				xxx						xx			
242	3.2			xx	x			xxx				x	x		xxx			x		x	
243	6.8	x	xx	xx				xxx				xxx		xxx				x		x	
244	7.2	xx	xxx					xx				x	x		xxx			x		x	
245	9.0	xx	xxx					xx							xxx			xx			
246	11.2	x	xx		xx	xxx						xxx	x					xxxx			
247	<2	x											xxx		x			xx			
248	38.4	xxx	xxx									xxx					x	xxx			
249	<2	xx	xxx										xxx					xx			
250	<2	xx	xxx	xx						x			xxx					xx			
251	<2	xx	xxx	xx									xxx					xxx			
252	14.8	xxx	xxx	xxx								xxx						xxxx			
253	<2												xxx					x			
254	20.2			xx		xx		xxxx				xxx	x					xx		xx	
255	<2						x	xxx					xxx					xx			
256	9.7								x				xxx					x			
257	<2			xx									xxx					x			
258	<2							xxx			x		xxx		x			x			
259	3.2							xx				x	xxx					xx			
260	6.7	xx	xxx	xx				xx					xxx					x			
261	<2	x	xx	xx									xxx					xx			
262	<2							x				x		xxx				x			
263	3.6								x				xxx					x			
264	5.0	x	xx					x					xxx					x			
265	22.0						xxx	xxxx				xxx						xx		xxx	
266	18.0			xxx				xxx				xxx						xxx			
267	6.5	x	xx	xxx				xxx					xxx		xx			xx			
268	2.5									x			xxx					x			
269	<2	x	xx	xx				xx					xxx					x			
270	11.5			xxx	x			xxx				xxx						xxx			
271	26.3			xxx			x	xxxx			xx	xxx						xxx			
272	<2			x					xx				xxx					x			
273	3.6			xxx				xxx					xxx					x			
274	6.5			xxx									xxx					x			
275	5.0	x	xx	xx									xxx					x			
276	11.5			xx				xxx				xxx	xx					xxx		x	
277	<2	x	xx	xx				xx		x			xxx					xxx			
278	3.6			xxx				xxx		x	xxx		xxx					xx			
279	3.2	x	xx	xxx						xxx			xxx					xx			
280	<2	xx	x	xx					xx	xxx			xxx					xxx			
281	21.2			xxx				xxxx				x	xxx					xxxx			
282	<2			xx				xxx			xx		x	xxx				xx			
283	<2			x									xxx					xxx			
284	18.3			xx				xxxx			xx	xxx						xxx		xx	
285	4.2	xxx	xxx	xx						xx			xxx					xx			

TABLE I—*Continued*

1. Serial Number	1. Radioactivity	3. Liquid Oil	4. Odor of Oil	5. Visible Fumes	6. Tarry Odor	7. Odor of Ammonia	8. SO_2 Odor	9. Sublimate	10. Odor of Scorching	11. Oil Odor when Broken	12. Other Odors	13. Shale and Clay	14. Lime or Dolomite	15. Sand	16. Silt	17. Chalk	18. Chert	19. Shade	20. Red	21. Green	22. Coal
286	3.9	xx	xxx	xxx						x			xxx					x			
287	<2	xx	xxx	xx				xx						xxx	x			x			
288	6.0	x	xxx	xxx									xxx					xx			
289	<2	xxx	xxx											xxx				xx			
290	5.4	x	x	xxx									xxx	x				xx			
291	3.9	xxx	xx											xxx				x			
292	6.0			xx		xxx		xx				xxx	xxx					xxx			
293	<2							xxx				x	xxx		xxx			x			
294	2.1												xxx					x			
295	<2	xx	xxx	xxx				xxxx			xx			xxx				xx			
296	7.0	xx	xx											xxx				xx			
297	25.9							x			x	x	xxx					xxx			
298	7.8							x				x	xxx					xxx			
299	5.1							x					xxx					xxx			
300	<2	xx	xx											xxx				xxxx			
301*	158	xx	xx	xxx														xxx			
302*	220	xxx	xx	xxx														xxxx			
303*	38.2			xx		x					xxx	xxx						xxx			
304*	21.2	xxx	xx									xxx						xxxxx			
305*	20.5	xx	xx	xxx							xx	xxx						xxxxx			
306*	34.2	xxx	xx	xxx								xxx						xxxxx			
307*	42.8	xx	xxx	xxx								xxx						xxxxx			
308*	25.2	x	xx								xx	xxx						xxxxx			
309*	104			xx		xx												xx			
310	21.3	xxx	xx	xx								xxx						xxxxx			
311	34.6	xxx	xx								xx	xxx						xxxx			
312	27.7	xxx	xxx	xx	x							xxx						xxxx			
313	42.1	xxx	xx	xx								xxx						xxxxx			
314	<2	x	xx	xx																	
315*	2.9	x	xx	xx								x				xxx		x			
316*	18.4			x		xx											xxx	x		x	
317*	5.0		xx	x									xx				xxx	xx			
318*	58.7	xxx	xxx	xxx								xxx						xxxx			
319*	8.3										x		xxx					xx			
320	8.4																				
321	7.0																				
322	7.5			xxx			xxx	xxxx				xxx						xx			
323	11.3			xx			xx	xxx				xxx			x			x			
324	12.4	x	xx					xxx				xxx			x			xxx			
325	8.4			xx			x	xxx				xxx						x			
326	11.2	x	xx	xx				xxxx				xxx		xxx				xx			
327	12.6	xx	xxx	xxx				xxx						xxx	x			xx			
328	6.6	xx	xx	xxx				xx							xxx			xx			
329	6.9	xx	xx					xx					x		xxx			xx			
330	7.8	x	xx					xxx				xxx						xxx			
331	10.5					xx		xxxx				xxx						x			
332	7.2	xx		xxx	xxx			xxxx				xxx						xxx			
333	7.5	xxx	xxx											xxx				xx			
334	12.3	xxx	xxx											xxx				xxx			
335	15.0	xx	xx										x	xxx				xx			
336	10.2	x		xxx	xxx	xxx		xxx				xxx		x				xx			
337	7.2					xxx		xxx				xxx	x		x			x			
338	8.4			xxx	x	x		xxx				xxx	x					xx			
339	5.2	x	xxx		xx			xx				xxx	x	x				x			
340	3.9	x	xxx			xxx		xxx				xxx	x					xxx			
341	5.7				xx	xx		xxx				xxx	x					x			
342	7.2	x			xx	xx		xxx				xxx		x				xx		xx	
343	6.0	x		xx		xxx		xxx				xxx		x	x			x			
344	6.4	xx	xx											xxx	x			x		x	
345	9.0	x	xx					xxxx				xxx		x	x			x		x	
346	5.4	x	xx					xxxx				xxx			x			x			
347	8.1		xxx			xxx		xxx				xxx		x				x		xx	
348	6.9	xx	xx					xxx				xxx		x	x			x		xx	
349	7.2	x	xx			xx		xxx				xxx		x	x			xx		xx	
350	9.6	xx	xx					xxx				xxx		x	x			xx		xx	
351	6.9	x	xx			xx		xxx				xxx		x	x			x			
352	8.7	x	xx					xxx				xxx		x	x			x		x	
353	5.4					xxx						xxx			x			x		x	
354	7.8	xx	xx									x		xxx	x			x		xx	
355	7.2	x	xx			x		xxxx				xxx		x	x			x		xx	
356	6.9	x	xx			xx		xxx				xxx		x	x			x		xx	
357	7.2	x	xx			xx		xxxx				xxx		x				x		x	
358	7.8	xx	xx			xx		xxx				xxx		x	x			x		x	
359	7.8	xx	xx			x		xxxx						xxx	x			x			
360	9.0	xx	xx											xxx	x			xx		xx	

TABLE I—*Continued*

1. Serial Number	2. Radioactivity	3. Liquid Oil	4. Odor of Oil	5. Visible Fumes	6. Tarry Odor	7. Odor of Ammonia	8. SO_2 Odor	9. Sublimate	10. Odor of Scorching	11. Oil Odor when Broken	12. Other Odors	13. Shale and Clay	14. Lime or Dolomite	15. Sand	16. Silt	17. Chalk	18. Chert	19. Shade	20. Red	21. Green	22. Coal
361	6.3	xxx	xxx										x	xxx	x			xx		xx	
362	6.6	xx	xx										x	xxx	x			xx			
363	6.6	xxx	xxx											xxx	x			xx		xx	
364	6.6	xxx	xx											xxx	x			xx		xx	
365	7.5	xxx	xx											xxx	x			xx		xx	
366	<2			xxx	xxx													xxxxx			xxx
367	<2			xxx	xxx													xxxxx			xxx
368	14.4							xxx			x	xxx						x			
369	80.4	xxx	xx								xx	xxx						xxxxx			
370	3.3				xxx													xxxxx			xxx
371	20.4																				
372	18.3																				
372A*	<2								x				xxx					xxx	xx		
373*	2.1												xxx	x	x			x			
374*	8.0					xx		xx				x	xxx					xxxx			
375*	3.9					x		x					xxx					xx			
376*	22.2					xxx						xxx						xxx	xx		
377*	9.9												xxx					xx			
378*	8.7					xxx						xx	xx					x			
379*	7.8												xxx					xx			
380*	<2								x	x			xxx					xx			
381*	<2																xxx	x			
382*	7.6	xxx	xxx									xxx						xxxx			
383*	6.3					x						x				xxx		x			
384*	7.2					xxx						xxx						x			
385*	13.8					x						xx	xx					x			
386*	5.4											xxx	xx					x			
387*	<2												xxx					x	xx		
388*	<2															xxx		x			
389*	4.5							xx						xxx				x	x		
390*	18.6					x		x				xxx						xx	xx		
391*	14.4					x						xxx						x			
392*	<2													xxx				x			
393*	4.2	xxx	xx											xxx				xxxx			
394*	7.2			xxx	xx							xxx						x			
395*	4.5					x						xx	xx		x			x			
396*	6.3							x				xx	xx					x			
397*	5.9											xx	xx					x		x	
398*	8.5			xxx	xx							xxx	x					xxx			
399*	8.6			xx	xx			x				xx	xx					x			
400*	5.6					x						x				xxx		x			
401*	6.6			xx	xx	xx						xxx	x					xxx			
402*	6.9			xx	xx			x				xxx	x					xxx			
403*	4.3			xx	xx							xxx	x					xxx			
404*	6.9					x						xxx	x					xxx			
405*	7.9											xxx	x					x			
406*	4.0											x				xxx		x			
407*	9.9					x		xx				xxx	x					xxx			
408*	9.9					xxx						xxx	x					xxx			
409*	10.2							xx				xxx						x			
410*	7.9	xx	xx									xxx			x			xx			
411	10.2					xx						xxx			xxx			xx			
412*	<2	xxx	xxx											xxx				xxx			
413*	8.9			xx	xx	xx						xxx			x			xx			
414*	12.5					x		xxx				xxx						x	x		
415*	10.2													xxx	x			x			
416*	10.2	xx	xx											xxx	x			xxx			
417*	9.6													xxx	x			xxx			
418*	15.2			xx	xx	x		xxx				xxx						x			
419*	6.6	xx	xxx											xxx	x			xxx			
420*	<2	xxx	xxx											xxx				xxxxx			
421*	5.3	xxx	xxx											xxx				xxx			
422*	8.6					x			x			xx	xx					x			
423*	12.9						xxx				xx	xxx						xx			
424*	6.9			xx		x		xxx				xxx						x			
425*	<2													xxx	x			x			
426*	7.3											xxx					x	xx			
427*	7.5																xxx	x	x		
428*	8.9	xxx	xxx									xxx						xxx			
429*	2.6	xxx	xxx																		
430*	8.3					xxx						xxx	x					x			
431	9.3											xxx			x			x		xx	
432	6.0	xxx	xxx				xxx							xxx				xxxx			
433	12.6						xxx	xxxx				x		xxx	x			x		xx	
434	10.5						xxx	xxxx				xxx		x				x		xx	

TABLE I—*Continued*

1. Serial Number	2. Radioactivity	3. Liquid Oil	4. Odor of Oil	5. Visible Fumes	6. Tarry Odor	7. Odor of Ammonia	8. SO_2 Odor	9. Sublimate	10. Odor of Scorching	11. Oil Odor when Broken	12. Other Odors	13. Shale and Clay	14. Lime or Dolomite	15. Sand	16. Silt	17. Chalk	18. Chert	19. Shade	20. Red	21. Green	22. Coal
435	5.1						xx	xx				xx	xx					x		xx	
436	7.8						xxx	xxxx				xxx						x		xx	
437	28.8						xxx	xxxx				xxx			x			x		xx	
438	8.7	xxx	xxx											xxx				xxx			
439	15.0			x			xx	xxxx				xxx		xxxx	x			x		xx	
440	26.1			xxx				xxx				xxx		xxx	x			x		xx	
441	11.4	xx			xx							xxx		xxx	x			x		xx	
442	10.8	x	xx					xx				xxx		xxx	x			x		xx	
443	12.0			xxx				xxxx				xxx						x		xx	
444	5.7	xxx	xxx											xxx				xxxx			
445	6.4	xxx			xx									xxx				xxx			
446	6.3						xx	xxx						xxx	x			x			
447	6.3							x			xx		xxx	x	x			x			
448	9.0							x			x	x	x		xxx			x			
449	9.6							xx			x		x		xxx			xx			
450	9.6			x	x	x									xxx			xx			
451	11.7			xxx	xxx			xx				xxx	x	xx	xx			xxx			
452	6.3				x			x					xx	xxx				x			
453	8.4	x	x	xxx	x			xx						xxx	x			xx			
454	10.8	xx	xx		xxx							xxx			xx			xxx			
455	9.0			xxx	xxx									xxx	x			x			
456	8.4			xxx	xxx							xxx			x			xxx			
457	7.5			xxx	xxx			xxx				xxx			x			xxx			
458	11.7			xxx	xxx							xxx			x			xxx			
459	15.6	xxx	xx	x								xxx	x	x	x			xxxx			
460	12.0	xxx	xx		xx							xxx			x			xxxx			
461	11.1			xxx	xx							xxx			x			xxx			
462	13.2			xxx	xxx							xxx						xxxxx			
463	18.0						xx	xx					x	xxx				x			
464*	12.9			xxx	xx			x			xx	xxx	x					xxx			
465*	2.1									xx			xxx					xxx			
466*	<2												xx				xxx	x			
467*	12.6		xx	xxx		xxx		xx				xxx						xxx			
468	5.7			xxx	xx			xxx				xxx		x	x			x			
469	<2	xxx	xxx	xxx																	
470*	13.2				xx							xxx					x	xxx			
471*	5.7										x	xx	xx					x			
472*	3.0	x		xxx						xxx				xxx				xxx			
473	11.1	x	xx	xx				xx				x		xxx				x			
474	7.4		xx	xxx				xxx			xxx	x		xxx				x		xx	
475	8.7			xxx				xxxx			xx	xxx		x				xx	xxx		
476	8.7			xxx				xxx			xx	x	x	xxx				x	xx		
477	10.2	x	xx					xxx				x		xxx	x			xx			
478	14.7		x	xxx				xxx				xxx		x	x			x			
479	6.0			xxx				xxx			xxx	x		xxx				x			
480	6.6	xxx	xxx					xx						xxx				xx			
481	6.9	x	xx					xxx			xxx			xxx				xx			
482	9.9			xxx				xxx			xxx	xxx						xxx			
483	4.5			xx				xx				xxx	xx					xx	xxx		
484	6.3							xxx			xxx	xxx		x				xx	xxx		
485	8.1							xxx			xxx	xxx		xx				xx	xxx		
486	<2							xxx			xxx	x		xxx				xx	xx		
487	5.4							xxx			xxx	x			xxx				xx	x	
488	6.6	xx	xx					xxx				x		xxx				x		xx	
489	4.5	xx						xxx				x		xxx				x			
490	12.6	x	xx	xxx				xxxx			xx	xxx						xxxxx			
491	11.1			xx				xxx			xx	xxx						xx	xxx		
492*	8.0							x				xxx						xx	xxx		
493*	7.9					x						xxx						xx	xxx		
494*	8.2					xx		x				xxx						xx	xxx		
495*	8.9			xx				xx				xxx						xx	xxx		
496*	7.8			x		x						xxx						xx	xxx		
497*	7.8			xx				xx			xx	xxx						xx	x		
498*	7.4			x		x						xxx						xx	xxx		
499*	7.1			x							x	xxx						xx	xxx		
500*	5.4			x							x	xxx						xx	xx		
501*	5.8			x							x	xxx						xx	xx		
502*	7.3											xxx					x	xx	xx		
503*	8.0			x							x	xxx						xx	xxx		
504*	8.7			xx				xxx			xx	xxx						xx	xxx		
505*	8.6			x								xxx						xx	xxx		
506*	8.0			x							x	xxx						xx	xxx		
507	<2																				
508	<2																				
509	<2																				
510	<2																				

5. *SO_2 odor* (Column 8).—This biting odor may be produced by the dissociation of iron sulphate, the oxidation of sulphur and sulphides as they are heated, as well as by certain types of organic matter.

6. *Sublimate* (Column 9).—A ring of white sublimate is more abundant in subsurface cores than in surface exposures, and also more common in marine than in fresh-water deposits. Sulphur may also produce a sublimate, which shows a yellow color if abundant. Some rocks produce a very abundant sublimate, possibly organic in origin. This is indicated by the symbol "xxxx" in Column 9. The ring of white sublimate appears to be generally produced by ammonium chloride or sulphur in varying proportions.

TABLE II

AVERAGE RADIOACTIVITES OF SAND-FREE SHALES OF VARIOUS ORGANIC CONTENTS

Type of Organic Matter	*No. of Samples*	*Average Radio-activity* $\times 10^{-12}$
Oil shale	21	34.3
No oil or oily odor	72	14.6
Tarry odor	21	13.2
Ammonia odor	28	13.4
Strong fumes, no distinct odor	49	15.3
SO_2 odor	14	16.8
Very abundant sublimate		
A. Dark to black	19	18.8
B. Medium to light	10	15.5
No sign of organic matter	8	11.8

TABLE III

EFFECT OF VARIOUS ORGANIC CONTENTS ON RADIOACTIVITY OF SAND-FREE, BLACK AND GRAYISH BLACK SHALE

Type of Organic Content	*No. of Samples*	*Average Radio-activity* $\times 10^{-12}$
Oil shale	19	36.8
Ammonia odor	7	14.6
Abundant fumes, no strong odor	9	18.4
Tarry odor, no liquid oil	3	20.2
Very abundant sublimate, no strong oil odor	2	24.7
SO_2 odor	1	23.7

7. *Odor of scorching* (Column 10).—The odor of scorching, occasionally produced by hard limestones, is probably produced by the destructive distillation of hydrocarbons or other organic matter.

8. *Oil odor when broken* (Column 11).—The oil odor when broken is the only one of the organic indices not produced by heating. It is generally yielded by hard limestones of the type which yield the scorching odor when heated.

9. *Other odors* (Column 12).—A few samples yield odors, apparently of organic origin, which do not belong to the previous classes.

Tables II and III summarize the relations between the radioactivity of shales and the different types of organic matter. The most striking feature is of course the high radioactivity of the rocks which yield oil on distillation. Dark shales which give no oil but a very abundant sublimate, probably of organic origin, also show a correlation with high radioactivity. The other types of organic matter

show no particular correlation with high or low radioactivities. However, it should be remembered that coals, which represent the most concentrated form of the organic matter yielding tarry odors, are of very low radioactivity.

Since black shales are both more radioactive and richer in organic content than the average, it is of interest to compare the radioactivities of the various types of organic matter in these rocks, as given in Table III, with those of the lighter-colored shales given in Table II. It is noteworthy that each type of organic matter is higher in radioactivity in the case of the black shales, suggesting that dark color is associated with higher radioactivity, regardless of the type of organic matter present.

Pontecorvo[7] has made a determination of the content of uranium, thorium, and potassium in a sample of the Chattanooga shale by the combined beta-gamma method he has already described.[8] The sample tested came from the same well as No. 47, of Table I. The results were: potassium 4.45 per cent, uranium 83×10^{-6}, thorium 85×10^{-6}, radium 29×10^{-12}. These figures indicate that most of the radioactivity was due to the uranium-radium series, though thorium is also highly concentrated, and potassium slightly above the average.

One of the most interesting and important problems relating to the radioactivity of sedimentary rocks is the explanation of the marked relation between radioactivity and organic content. While this relation is a fact, the reasons for it are a matter of conjecture. As Table II indicates, the relation between organic content and radioactivity varies greatly with the type of organic content. Shales which yield oil when distilled are in general much more radioactive than those containing other types of organic matter. The shales listed in Table II containing other types of organic matter are little, if any, higher in radioactivity than ordinary shales. Coals, though they consist of an even larger percentage of organic matter than the bituminous shales, are among the least radioactive rocks tested; most of them have too little radioactivity for the apparatus to measure. It is clear, therefore, that one type of organic matter, the bituminous material of oil shales, is associated with very high radioactivity, others with more or less normal radioactivity, and still another type of organic matter, the coals, with abnormally low radioactivity. It should be understood that by oil shale as used in this paper is meant marine oil shale. Cannel coal, which yields oil on distillation, but is of fresh-water origin, is very low in radioactivity, which suggests that oil shales of fresh-water origin would also be of low radioactivity. Of course not all the oil shales which give high radioactivities are known to be of marine origin; it is known that some of them are marine, and indirect evidence suggests that all of them are.

Three possible causes for these relations may be mentioned. One is that the radioactivity of the oil shales is due to the mineral constituents, particularly the

[7] Bruno Pontecorvo, unpublished manuscript, dated February, 1941.

[8] *Idem*, "Radioactivity Analyses of Oil Well Samples," *Geophysics*, Vol. 7, No. 1 (January, 1942), pp. 90–94.

heavy minerals, and that the radioactive matter was not deposited from solution, but has always remained in the mineral grains since they left the igneous rocks in which they were formed. According to this theory, the high radioactivity of the mineral grains of the oil shales is due to their extreme fineness. Since the highly radioactive, hard, and insoluble minerals of igneous rocks tend to become more radioactive as they become finer, and since the organic content of marine sediments increases as they become finer, there is some reason for supposing that the clastic particles of marine oil shales would be both finer and more radioactive than those of ordinary shales.

The other two theories assume that the radioactive matter in the bituminous shales is chiefly deposited from solution. According to one explanation, it is extracted from solution by some of the same organisms whose remains form the oil shale, much as certain sea weeds extract iodine from sea water. According to the other hypothesis, the same chemical environment which was favorable for the accumulation of oil shale was favorable for the precipitation of uranium and thorium from solution. Possibly it was the highly reducing character of the waters in which the black shales were deposited which produced the precipitation. Another possible explanation of the means of precipitation is given by Beers and Goodman[9] and Beers,[10] who show that uranium and thorium compounds may be precipitated from solution in a colloidal form when the pH of the solution exceeds a certain amount, and suggest that this accounts for the abnormally high uranium and thorium content of the marine bituminous shales. Beers[11] also mentions that certain clay minerals will absorb large amounts of uranium and thorium salts from solution.

The fact that certain types of organic matter are not associated with high radioactivities suggests that the radioactive elements were deposited from solution, for different organisms and different chemical environments could easily alter the types of organic matter and amounts of the radioactive elements precipitated. The occurrence in the oil shales of concretions of much higher radioactivity than the oil shales themselves furnishes another argument in favor of deposition from solution. The radioactive matter in these concretions clearly represents a concentration by solution of the uranium and thorium in the oil shales, and it appears that if these elements had been held in the oil shales in minute, highly insoluble minerals, they could not have dissolved with sufficient readiness to be concentrated in the concretions. On the other hand, if the minute mineral grains had not been highly insoluble, the radioactive matter would have been dissolved out during the weathering of the original igneous rock and the transportation of the grains. Furthermore, if the high radioactivity of the marine

[9] Roland F. Beers and Clark Goodman, "Distribution of Radioactivity in Ancient Sediments," *Bull. Geol. Soc. America*, Vol. 55 (1944), pp. 1229–53.

[10] Roland F. Beers, "Radioactivity and Organic Content of Some Paleozoic Shales," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 1 (January, 1945), pp. 1–22.

[11] *Ibid.*, p. 15.

oil shales is a consequence of the extremely small size of the clastic particles in them, it would be expected that other extremely fine sediments would also be very high in radioactivity. However, in the case of the extremely fine-grained deep-sea deposits, the meager evidence suggests that the uranium content, at least, is about normal for a shale.

It seems that a simple chemical experiment might settle this question. If the uranium and thorium of oil shales dissolves readily in acids or other suitable chemical reagents, it has probably been deposited from solution; if these elements dissolve with great difficulty, a clastic origin may be suggested.

RELATIVE RADIOACTIVITIES OF IGNEOUS AND SEDIMENTARY ROCKS

Because of a misunderstanding of the relations, there appears to have been a widespread idea that sediments are less radioactive than the igneous rocks from which they were derived. For example, Piggot and Urry[12] state that the sediments have only one-tenth the radioactivity of igneous rocks. This is one of the most important problems in the whole subject, and is worth discussing in detail.

The best method for clarifying the matter is to consider the sources of the radioactive matter now in the sediments, the disposition of the radioactive matter in the igneous rocks when they are eroded, and the effect of any dilution or concentration of the radioactive matter in the igneous rocks on entering the sediments. When the radioactive matter of igneous rocks is eroded, it must enter the sediments, the oceans, or the atmosphere, for there is clearly no other place for it to go. In estimating the comparative radioactivities of igneous and sedimentary rocks, it is important to know the content of radioactive elements in the atmosphere and oceans, for if some of the radioactive matter remains permanently in the oceans, there is less for the sediments, while if the amount in the oceans and atmosphere is negligible compared to that in the sediments, the problem is greatly simplified.

It seems clear that the content of radioactive matter in the atmosphere is so small compared to that in the sediments that it may be neglected. The mass of the atmosphere is equivalent to the mass of a layer of sediments only about 14 feet thick around the earth; the solid content of the atmosphere in the form of dust is very low, and this dust is not known to be highly radioactive.

In order to compare the mass of radioactive matter in the ocean and the sediments, it is necessary to know the mass of the sediments and the average concentration of radioactive matter in them, and the average concentration and mass or volume of either the ocean or its salts. The average thickness of the sediments on the continents may be estimated roughly, but the thickness in the much larger ocean basins is not even vaguely known. It was formerly supposed that the thickness of the deep-sea deposits was negligible, but recent investigations by Piggot and Urry[13] show that they were deposited much more rapidly than had

[12] C. S. Piggot and Wm. Urry, "Radioactive Relations in Ocean Water and Bottom Sediment," *Amer. Jour. Sci.*, Vol. 239 (1941), pp. 81–91.

[13] C. S. Piggot and Wm. Urry, "Time Relations in Ocean Sediments," *Bull. Geol. Soc. America*, Vol. 53 (1942), p. 1206, Table II.

previously been supposed. The rates of deposition, which Piggot and Urry measured accurately for the first time by the decrease in radioactivity with depth, suggest an average accumulation of 1 to 10 centimeters per thousand years. Since 1 centimeter per 1000 years would amount to 10 kilometers in a billion years, these new data suggest enormous thicknesses. Although the average rate of deposition during geologic time may have been slower, it appears that the greater part of the volume of sedimentary rocks is in the ocean basins. In view of these considerations, the figure mentioned by Clarke[14] of an average thickness of 2225 feet of sedimentary rock over the earth is a minimum. This, however, would result in a volume of 84,000,000 cubic miles of sediments, while the saline matter of the ocean, if evaporated to dryness, would occupy a volume of 4,800,000 cubic miles;[15] its average content of potassium is about 1.1 per cent. According to Foyn, Karlik, Petterson, and Rona,[16] the average content of radium in the sea is 0.07×10^{-12} gram per liter, and of uranium 2×10^{-6} gram per liter. The volume of the ocean is 302,000,000 cubic miles, or 3.6 times the minimum volume of the sediments, which may be assumed to contain approximately 2×10^{-6} gram per gram of uranium. According to the data just cited, the sediments contain at least 600 or 700 times as much uranium, and 30 or 40 times as much potassium as the oceans.

No reliable figures are available for thorium, and it is likely that the short-lived elements such as radon and thoron are not in equilibrium with the uranium and thorium in the ocean. Hence, determination of uranium and thorium based on radon and thoron might be in error. However, it is known from studies of radioactivity well logs that evaporates are of much lower radioactivity than the average sedimentary rock. Since the volume of the sediments is at least 15, and may be 150, times the volume of all the saline matter in the ocean (evaporateed to dryness) and since the radioactivity logs suggest that this saline matter is less radioactive than the average sedimentary rock, it is clear that all the radioactive matter in the ocean is of negligible mass, compared with the mass in the sediments. Accordingly, for rough calculations which are all that can be made with the present data, the radioactive matter that remains permanently in the oceans does not need to be considered in comparing the relative radioactivities of sedimentary and igneous rocks.

Let the source of the radioactive matter now in the sedimentary rocks be considered. It seems evident that the only possible sources of appreciable quantities are: (1) the weathering of igneous rocks; (2) pyroclastic materials; (3) the emanations from volcanoes, fumaroles, and deep-seated springs; (4) the erosion of veins and other deposits made by magmatic solutions; and (5) the radioactive matter in the oceans and atmosphere when the earth first cooled.

The next step is to consider how the concentrations of radioactive matter might be altered by weathering, deposition, and metamorphism. While large masses of sediments have doubtless been altered to metamorphic rocks, or fused

[14] F. W. Clarke, "Data of Geochemistry," *U. S. Geol. Survey Bull.* 770 (1924), p. 22.

[15] *Ibid.*, p. 152.

[16] Foyn, Karlik, Petterson, and Rona, *Nature*, 143 (1939), pp. 275–76.

to become igneous magmas, this would not affect the average concentration of radioactive matter in the sediments unless the sediments so altered were higher or lower than the average. There is at present no reason to think that this was the the case. On the other hand, it seems fairly certain that there is a loss in concentration of radioactive matter as it passes from igneous to sedimentary rocks, as a result of oxidation, hydration and combination with carbon dioxide. This loss in concentration may be considerable, possibly as much as 25 per cent, but even this figure is less than the present uncertainty as to the average amount of radioactive matter in the igneous rocks from which the sediments were derived.

The mass of radioactive matter in sediments is also increased by the volcanic ash and various other pyroclastic materials, incorporated in them. Though these are also of igneous origin, their effect must be considered separately, because the igneous rocks with which the sediments are to be compared are mostly intrusive. The pyroclastic materials will not change the average concentration of radioactive matter in the sediments unless they are higher or lower than the average. While radioactivity logs and sample tests show that some volcanic ashes and bentonites are more radioactive than the average sediment, the data are insufficient for a general conclusion.

It is unlikely that the vein and other solid deposits made by solutions of igneous origin are sufficiently abundant to have an appreciable effect on the average concentration of radioactive matter in sediments, but the case is different with the emanations of volcanoes and fumaroles, for these emanations have continued throughout geologic time. If the radioactive elements in such emanations are not diluted by large volumes of solid matter, they could increase the average concentration of radioactive matter in the sediments.

It is possible that the amount of radioactive material originally present in the oceans when the earth first cooled was sufficiently large to make a considerable increase in the mass, and also the concentration of the radioactive matter in the sedimentary rocks. The occurrence of radioactive minerals in pegmatites and in some vein deposits of magmatic origin suggests that under certain conditions at least the radioactive matter is concentrated in the last fluids to solidify as the magma cools. If this took place on a grand scale during the first solidification of the rocks of the earth from a molten state, the final magmatic fluids may have contained much radioactive matter together with abundant water, and may have mingled with the primordial ocean.

It is apparent from the preceding discussion that some causes may have operated to increase the concentration of radioactive matter in the sediments compared with that of the igneous rocks from which they were derived, others to decrease it. In spite of the many uncertainties, it would appear most likely from these theoretical considerations that there would be no marked difference in concentration.

It is apparent that the volume and radioactivity of the deep-sea deposits have an important bearing on this problem. It seems likely from the rates of dep-

osition described by Piggot and Urry, and mentioned previously, that by far the greater part of the sedimentary rocks are in the ocean basins. Accordingly, it is the radioactivity of these rocks in the ocean basins which chiefly determines the radioactivity of the sediments as a whole, and any excess or deficiency of the radioactive matter on the continents (compared with the igneous rocks) could be counterbalanced by an opposite but smaller variation in the concentration of radioactive matter in the deep sea deposits.

It has only recently been learned through the work of Piggot and Urry[17] that the high radioactivity of the uppermost strata of the deep-sea deposits is due to the deposition of excess radium and ionium not in equilibrium with the uranium present. The few available tests of radioactivity of the deep-sea deposits below this superficial layer do not suggest that the concentration of uranium and potassium is any greater than that of shaly and limy deposits of the continental platforms. However, as Goodman[18] has pointed out, since thorium is an isotope of ionium, the deposition of such excess quantities of ionium in the deep-sea suggests that high concentrations of thorium have also been precipitated. Hence, although no determinations of thorium in the deep-sea deposits are available to the writer, it might be expected that the deep-sea deposits will be rich in thorium, with a corresponding deficiency on the continental platforms. Aside from this consideration, there is no definite reason for supposing that the radioactivity of deep-sea deposits is greater or less than that of the deposits of the continental platforms.

The preceding discussion has shown that there is no theoretical basis for supposing that the radioactivity of sedimentary rocks is either much less or much greater than that of the igneous rocks from which they were derived. It is of interest to ascertain how the actual tests of samples support this conclusion, and the 510 radioactivity determinations made by the writer, and cited in Table I, afford a means of making this comparison. However, five operations must be performed before a direct comparison can be made. In the first place, it is necessary to assume some type of igneous rock as typical of the average source of the sediments. In the following discussion, it is assumed that this rock is granite. The next step is to obtain the equivalents of each unit of gamma-ray intensity, in which the radioactivities are expressed in this paper, in terms of percentages of radioactive elements. According to Pontecorvo,[19] one radium equivalent $\times 10^{-12}$ gram per gram, as used in this paper, is produced by the following concentrations of radio-elements in equilibrium with other members of their series, if any: 1×10^{-12} gram per gram of radium, 2.8×10^{-6} gram per gram of uranium, 5.7×10^{-6} gram per gram of thorium and 0.8×10^{-2} gram per gram of potassium.

The average radioactivity of granites is given by Goodman and Evans[20] as

[17] C. S. Piggot and Wm. Urry, *op. cit.*, p. 1190.

[18] Clark Goodman, "Geological Applications of Nuclear Physics," *Jour. Applied Physics*, Vol. 13 (1942), p. 286.

[19] Bruno Pontecorvo, unpublished manuscript, February 21, 1941.

[20] Clark Goodman and Robley D. Evans, "Radioactivity of Rocks," *Bull. Geol. Soc. America* 52 (1941), pp. 459–90.

1.37×10^{-12} gm./gm. radium which equals 1.37×10^{-12} unit, and 13×10^{-6} gm./gm. thorium which equals 2.3×10^{-12} unit. According to Jeffries,[21] granites contain about 3 per cent potassium, or 3.8×10^{-12} gm./gm. radium equivalents. The total radium equivalents of the granite are therefore 7.5×10^{-12}.

The average abundance of shale, sandstone, and limestone on the continental platforms is estimated by Kuenen,[22] on the basis of measured sections, to be, respectively, 24, 14, and 17. Accordingly, the following relations may be tabulated.

Rock Type	*Relative Abundance on Continental Platforms*	*Radium Equivalents* $\times 10^{-12}$	
		(*A*)	(*B*)
Shale	24	16.2	12.0
Sandstone	14	5.3	5.3
Limestone	17	4.1	4.1
Weighted average		10.0×10^{-12}	7.9×10^{-12}

In the foregoing list, Column A gives the actual averages of all the shales tested, which was 16.2. However, since an effort was made to secure samples of black shales, which are much more radioactive than the average, this figure is almost certainly higher than the average for all shales. Accordingly, it seems that the figure of 12.0 units of radioactivity, or radium equivalents times 10^{-12}, is close to the actual average for shales. By using this figure, as in Column B, the average radioactivity of the sediments of the continental platforms becomes 7.9. which is close to the figure of 7.5 obtained for the granites. While this close agreement is doubtless a coincidence, the above calculation nevertheless supports the idea that there is not much difference in radioactivity between the sediments and the igneous rocks from which they were derived.

RELATION OF RADIOACTIVITY TO AGE

The Paleozoic shales average higher in radioactivity than those in the Cenozoic, and there is also more contrast in radioactivity between the different strata of the older era. Aside from the possibility that a large concentration of radioactive matter occurred in the primordial ocean, there is no reason to expect that there will be an increase of radioactivity with age, and it seems likely that the differences are produced by variations in conditions of sedimentation and types of life existing, rather than by any direct effect of age. Most of the Paleozoic samples were collected from the central part of the United States, and were deposited during the slow subsidence of a relatively stable platform. These conditions presumably favored chemical decomposition of the sediments, a high degree of sorting, and also the delicate balance between subsidence and deposition necessary for the deposition of oil shales of the Chattanooga type. The dominant type of organic life existing in the seas has varied with geologic time, and this in

[21] Harold Jeffries, "The Thermal State of the Earth," *Amer. Jour. Sci.*, Vol. 239 (1941), p. 831.

[22] Ph. H. Kuenen, "Geochemical Calculations Concerning the Total Mass of Sediments in the Earth," *Amer. Jour. Sci.*, Vol. 239 (1941), p. 168.

turn has influenced the distribution of radioactive matter among the different types of sedimentary deposits, although it could hardly have affected the total amount of radioactive matter deposited. A good example of this influence of organic life is the development of pelagic foraminifera in the Cretaceous. According to Kuenen,[23] before the Cretaceous, the limestones were deposited chiefly on the continental platforms, but since the beginning of that period the pelagic foraminifera have caused the limestones to be laid down chiefly in the ocean basins, with a corresponding scarcity of lime in the Cretaceous and Tertiary deposits of the continents.

RELATION OF RADIOACTIVITY TO RATE OF DEPOSITION

The deep-sea deposits furnish an important clue to the relation between radioactivity and rate of deposition. Until very recently it was generally supposed that deep-sea deposits were both highly radioactive and deposited very slowly. As Weaver[24] pointed out, this would suggest that high radioactivity and slowness of deposition go together. However, Urry and Piggot[25] have recently shown by measurements on cores that the high radioactivity is confined to the uppermost few feet of these deposits. The reason for the rapid decrease of radioactivity with depth is that the excess in the uppermost layers is due to radium, which is half disintegrated in 1600 years, and ionium, with a half life of 82,000 years. Thus, in a few hundred thousand years this excess radium and ionium have practically disappeared, and the concentration of these two elements which remains is merely that which is in equilibrium with the uranium present. Clearly this part of the deep-sea deposits in which the ionium and radium are in equilibrium with the uranium present forms by far the greater part of the bulk of these sediments, and clearly only this equilibrium radioactivity should be compared with that of the deposits of the continental platforms, to determine the effect of rate of deposition on radioactivity. Unfortunately, only a few determinations of the radioactivity of the uranium-radium series in this part of the deep-sea deposits which has reached equilibrium are available. They do not indicate any higher radioactivity than in rocks of similar lithologic type laid down on the continental platforms. The few potassium analyses made of deep sea sediments also suggest no higher concentration than would be found in the shallow-water deposits.

No determinations of the thorium concentration in deep-sea deposits are available to the writer. However, as Goodman[26] pointed out, since thorium is an isotope of ionium, the fact that high concentrations of ionium are deposited in the deep-sea deposits suggests that they are also very rich in thorium. Hence, in spite of the lack of determinations of thorium in the deep-sea deposits, it might be

[23] Ph. H. Kuenen, *op. cit.*, p. 184.

[24] Paul Weaver, "The Theory of the Distribution of Radioactivity in Sedimentary Rocks," *Geophysics*, Vol. 7 (1942), pp. 192–98.

[25] C. S. Piggot and Wm. Urry, "Time Relations in Ocean Sediments," *Bull. Geol. Soc. America*, Vol. 53 (1942), p. 1190.

[26] Clark Goodman, *op. cit.*, p. 286.

expected that they will run high in thorium, with a corresponding deficiency in the sedimentary rocks of the continental platforms. Thus, the meager evidence regarding the radioactivity of deep-sea deposits suggests that they are normal or below normal in the case of two of the important radioactive elements, and probably high in the case of the third. As a result of this new information, the most important support for the theory that high radioactivity and slow deposition go together is removed.

In a previous paper,[27] the writer showed a figure illustrating long distance correlation of radioactivity logs in an area in Oklahoma. Many people have interpreted these logs as indicating that the Woodford or Chattanooga shale was of lower radioactivity where thicker and therefore presumably deposited more rapidly. Radioactivity logs may, of course, be used to indicate with considerable accuracy the relative radioactivity of a formation, provided that the changes in horizontal scale or sensitivity are allowed for. Radioactivity well-logging instruments are equipped with a device which will change the horizontal distance representing a given change in radioactivity, in other words, cause a peak or shift due to a given change in the radioactivity of the rocks to be large or small in actual size in inches on the paper. Thus, the fact that a given peak of radioactivity is large or small on different logs means nothing unless the changes in scale are taken into account. The small deflection opposite the Chattanooga in the radioactivity log of the well in the Deep Fox field could therefore be due to either the Chattanooga being less radioactive or to the log being run on a smaller scale, that is, with less horizontal distance representing a given change in radioactivity.

Actually, it is known that the well in the Deep Fox field was run on a smaller or less sensitive scale than the other logs because the instrument was not functioning properly. There is no direct indication of how much the scale was reduced in the log of the Deep Fox pool, but a rough idea of it might be obtained by comparing the deflection due with the Chattanooga shale with the deflection in passing from the Viola limestone to the Sylvan shale. By assuming that each log was run on the same scale throughout, and that the difference in radioactivity between the Sylvan shale and Viola limestone is everywhere the same, it should be possible to determine the relative radioactivities of the Chattanooga in the different wells logged by comparing the shift at the Viola-Sylvan contact with the shift produced by the Chattanooga shale. Obviously, in this case dividing the second shift by the first would give a quotient proportional to the radioactivity of the Chattanooga. Of course we do not know that the shift at the Viola-Sylvan contact remains the same, but at least these results are the most accurate that can be obtained with the available data.

In Table IV the second column shows the deflection, in inches on the original logs, produced by passing from the Viola to the Sylvan, the third column the deflection produced by the Chattanooga, and the fourth column the results of dividing the latter by the former. This result should be proportional to the radio-

[27] William L. Russell, "Well Logging by Radioactivity," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 9 (September, 1941), Fig. 5, p. 1787.

activity of the Chattanooga, according to the assumption. These figures in the fourth column suggest that the Chattanooga is more radioactive where thick than where thin, and that the appearance of low radioactivity in the Chattanooga in the third radioactivity log is due to the fact that it was run on a less sensitive scale, that is, a certain change in gamma-ray intensity is represented by a shorter horizontal distance. This increase of radioactivity in the Chattanooga in the Deep Fox pool occurs in spite of an increase in the chert content of the formation in that locality. Since the chert is very weakly radioactive, any increase in the radioactivity of the formation as a whole must be still more pronounced in the shale.

TABLE IV

RELATION BETWEEN THICKNESS AND RADIOACTIVITY OF CHATTANOOGA SHALE IN FOUR WELLS IN OKLAHOMA

Location	*Inches Deflection, Viola-Sylvan*	*Inches Deflection, Sylvan-Chattanooga*	*Column 3 Column 2*	*Thickness of Chattanooga in Feet*
Sec. 24, T. 14 N., R. 10 E., Creek Co.	1.6	3.4	2.1	35
St. Louis field, Pottawotomie County	1.2	2.0	1.7	185
Deep Fox field, Carter County	0.5	1.8	3.6	370
Cumberland field, Marshall County	1.0–2.5?	7.0	2.6–7.0?	265

The sample tests listed in Table III of the previous paper,[28] though too few to be conclusive, also suggest that the Chattanooga is more radioactive where thicker. The samples from areas where the Chattanooga is about 100 feet or less in thickness, as in northeastern Oklahoma and southwestern Kentucky, show less radioactivity than those from areas where it is several hundred feet thick, as in the Arbuckle region of Oklahoma and the Appalachian geosyncline of eastern Kentucky.

In spite of this evidence that radioactivity increases with rate of deposition, or at least with thickness, there is some evidence that the Chattanooga and possibly some of the other highly radioactive marine oil shales were deposited slowly. The Chattanooga, for example, is equivalent to a much thicker stratigraphic section in the eastern part of the Appalachian geosyncline.

A possible explanation of the occurrence of greater radioactivity with greater thickness in marine shales may be found in Trask's[29] observation that in recent marine deposits sediments deposited in depressions in the ocean bottom have more organic content than the shales deposited on the surrounding more elevated parts of the bottom. Such deposits in depressions presumably accumulate more rapidly and to greater thickness than those of the surrounding areas, and if the shale was bituminous it would presumably contain more bituminous matter in the depressions. Since radioactivity increases with bituminous content in marine shales, the shales which were deposited more rapidly would in such cases be more radioactive.

[28] William L. Russell, *op. cit.* (April, 1944), Table III.

[29] P. D. Trask *et al.*, "Geology and Biology of North Atlantic Deep Sea Cores, Part 8, Organic Content," *U. S. Geol. Survey Prof. Paper 196-E*, p. 142.

The general conclusions suggested by the foregoing considerations are that the supply of radioactive matter in solution limits the rate at which highly radioactive deposits can accumulate. In the case of radioactive matter in clastic sediments, the rate of deposition probably has little effect on the radioactivity, for the radioactivity in such strata would depend on the concentration of radio-elements in the clastic particles themselves, and, aside from the effects of solution, this concentration would be the same regardless of how fast the particles were laid down. Presumably the radioactive matter of sandstones is in such clastic particles. In the case of the highly radioactive oil shales, however, the radioactive matter may be deposited from solution, and the rate of deposition of such rocks is evidently limited by the rate at which the dissolved radioactive matter is transported in by the water. It is therefore possible that of two oil shales of similar organic content one will have much lower radioactivity simply because it was deposited too rapidly to acquire much radioactive matter, or because the waters in which it was laid down transported radioactive matter too slowly. If the radioactive matter in solution is brought in by currents in sufficient quantities, it is the chemical nature of the environment rather than the speed of deposition which controls the concentration of the radioactive matter.

RELATION OF RADIOACTIVITY TO ORIGIN OF OIL AND OF HELIUM IN NATURAL GAS

The radioactivity of sedimentary rocks has a bearing on the origin of oil because of the possibility that the source rocks of oil may be indicated by their abnormally high radioactivity, and because of the possibility that the radiations may play a role in the origin of oil or gas through their chemical action on the source rocks or on the hydrocarbons after they have formed. Of the various types of sedimentary organic matter previously described, the only variety which can be recognized by radioactivity measurements is marine oil shale, or shale yielding oil on distillation. Since shales of this character may generally be recognized on radioactivity logs made through casing, the radioactivity logs would be of value for indicating the source rocks of oil if it could be shown that oil was generated from bituminous shales to any marked degree. However, it does not appear that the source rocks of oil are at present well enough known to warrant the positive statement that oil has been generated extensively from bituminous shales.

The theory that alpha rays from elements of the uranium and thorium series have been effective in generating oil or gas has recently been discussed by Sheppard[30] and Beers.[31] By making certain favorable assumptions, Sheppard arrived at figures indicating that a considerable percentage of the organic matter in sediments has been chemically altered by the alpha rays. However, as Sheppard[32]

[30] C. W. Sheppard, "Radioactivity and Petroleum Genesis," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 7 (July, 1944), pp. 924–52.

[31] Roland F. Beers, "Radioactivity and Organic Content of Some Organic Shales," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 1 (January, 1945), pp. 1–22.

[32] C. W. Sheppard, *op. cit.*, p. 946.

states, large uncertainties exist in the quantities and assumptions which enter into the equations on which the calculations are based. With the present evidence, it does not appear possible to determine the exact nature of the chemical reactions that may be produced, or to assign any definite value to the percentage of organic matter present that has been altered in a given time. In view of these uncertainties, it may be worth while to consider the geologic evidence bearing on the problem.

The products of the chemical reactions produced by the bombardment of hydrocarbons by alpha particles contain a large percentage of hydrogen, and are thus strikingly unlike natural gas and petroleum, which are generally devoid of uncombined hydrogen. It does not appear that this absence of hydrogen is due to its escape by diffusion, for in South Africa there are a number of seeps and showings of gas containing hydrogen.[33] These occurrences are associated with igneous intrusions of Jurassic age, and it is probable that the gases containing the hydrogen were produced by the dissociation of the organic matter in the intruded sediments by the heat from the intrusions. The fact that this hydrogen has remained in the natural gas since the Jurassic without escaping or combining suggests that its absence in ordinary natural gas means that it was never generated.

The mineral thucolite may throw important light on this problem. Combined carbon and hydrogen, solid hydrocarbons, and a concentration of uranium and thorium about a thousand times greater than that in a highly radioactive oil shale have existed together in this mineral for a length of time that is probably considerably greater than the age of the source rocks in many oil fields. If the alpha rays cause the generation of oil or gas from the solid organic matter of the oil shales, one would think that the solid hydrocarbons or carbon and hydrogen of the thucolite would have been similarly altered, particularly as the rate of alteration should be around a thousand times faster. Furthermore, the kolm[34] in the Cambrian of Sweden still contains about 20 per cent of volatile organic matter, though its age is about 400,000,000 years and its content of uranium 0.46 per cent, or around 30 times as much as a highly radioactive marine oil shale contains.

If petroleum has been produced by the action of alpha rays, the time of its generation in certain oil fields is rather difficult to explain. In certain areas there is good evidence that oil has been generated and accumulated soon after the deposition of its source rocks, and that during the relatively long interval of subsequent geologic time no oil has accumulated. The highly radioactive and bituminous Chattanooga shale of eastern Kentucky and West Virginia is in itself the producing reservoir rock of an extensive gas field. The fact that so much gas practically devoid of oil is produced from the Chattanooga suggests that it has been the source of gas and not of oil.

[33] M. Rindl, *The Medicinal Springs of South Africa.* South African Railways and Harbors Administration (1933).

[34] Arthur Holmes, "Radioactivity and Geological Time," in "The Age of the Earth," *Natl. Research Council Bull. 80* (1931).

The geologic criteria by which it may be possible to estimate the importance of alpha rays in generating oil and gas consist primarily in the relation of the oil and gas producing formations to the organic materials of high, low and normal radioactivity. Several types of organic matter listed in Table I are not associated with high radioactivities. If oil or gas fields are markedly associated with organic matter of these types, or if the oil and gas pools occur in areas devoid of the highly radioactive bituminous shales, it would be clear that high radioactivities are not necessary for a source rock. If it could be shown that radioactive bituminous shales have generated oil and gas in certain cases, this would not prove that alpha rays are responsible, for the organic matter in the oil shales might have generated the hydrocarbons even if no radioactive matter had been present. Hence, this type of evidence would be chiefly negative. Although the present evidence is too meager to warrant a definite conclusion, it suggests that oil and gas may form from organic matter of both high and normal or low radioactivity. The best method for obtaining evidence on this point appears to be by the study of well logs showing natural radioactivity, which now provide a wealth of data in many fields.

It is fairly certain that organic matter in buried sediments generates hydrocarbons through processes which have no connection with radioactivity. Organic matter of all types loses its volatile constituents and progressively approaches a graphite in composition as the depth of burial, folding and regional alteration increase. Much of this volatile organic matter must have been expelled as hydrocarbons; yet the process has nothing to do with radioactivity, for it affects all types of organic matter, whether associated with high or low radioactivity.

The discovery that oil shales are generally the most radioactive portions of the sedimentary column naturally focuses attention on them as possible sources of the helium in natural gas. However, there seems to be no tendency for helium-bearing gas to be associated with oil shales or other rocks known to be highly radioactive. It is possible that any helium formed has been so diluted by hydrocarbon gases generated from the oil shale that it is present as mere traces. The abundant nitrogen associated with the helium also presents a problem, if it is of organic origin. Fortunately, this nitrogen affords a means of determining whether the nitrogen-and-helium-rich natural gas was formed in the sediments or is of deep-seated origin. As Rogers[35] pointed out, nitrogen and the inert gases of the helium group, except helium, have in gas from deep-seated sources a fixed ratio to each other which is approximately the same as in air. Thus, if this same ratio was found for the nitrogen and inert gases in natural gas, both the nitrogen and the helium are probably abyssal in origin, while if the nitrogen is present in much greater amounts than the usual ratio indicates, the nitrogen and helium probably formed in the sediments.

The fundamental question to be decided about the origin of the helium in

[35] G. Sherbourne Rogers, "Helium-Bearing Natural Gas," *U. S. Geol. Survey Prof. Paper 121* (1921), p. 16.

natural gas is whether it originated from radioactive matter in the sediments or came up from deep-seated sources below the sedimentary rocks. While more data than are available at present are doubtless needed to solve this problem, a few observations may be made which have some bearing on it. In the first place, it appears that there is no relation between the concentration of uranium and thorium in sedimentary rocks and the percentage of helium in the associated gas. Furthermore, the radioactivity logs in areas of helium accumulation do not, as far as known, indicate any exceptionally radioactive rocks, aside from the oil shales. The occurrence of highly radioactive precipitates from waters associated with oil, as at Barbers Hill, Chambers County, Texas, mentioned by the writer[36] in the previous paper, suggest the possibility that helium could have ascended from great depths. The high concentration of radioactive elements in the precipitates suggests the possibility of a high concentration of helium in association with the source from which the radioactive elements came. The deep-seated source of the radioactive material at Barbers Hill has not been established; however, a thorough investigation of this deposit would have an obvious bearing on the origin of the helium in natural gas.

A calculation of the amount of sediments needed as a source for the helium in a natural-gas pool also throws light on the problem. The average sedimentary rock produces about as much helium as it would if it contained about 10^{-12} gram of radium per gram of rock with 10^{-11} gram per gram as a maximum. This is equivalent to a production of about 2×10^{-4} or 2×10^{-3} cubic centimeter of helium per cubic centimeter of rock in 100 million years. However, in 100 million years it is quite likely that a weight of organic matter equivalent to at least 0.1 of the weight of the rock would be converted to natural gas. Since this would have a volume at atmospheric pressure of about 2 cubic centimeters per cubic centimeter of rock, the helium would comprise only about 0.01 to 0.1 per cent of the natural gas, even if all the helium generated were released from the rock.

It is also of interest to estimate the volume of sedimentary source rock needed to furnish the helium of a helium-gas field. If the percentage of helium in the gas was 5 per cent, the thickness of the reservoir 20 feet, the porosity 20 per cent, and the pressure 100 atmospheres, the helium present would be equivalent to a pure layer 20 feet thick at atmospheric pressure. Since not all the helium generated escapes from the rock, since some remains dissolved in the associated waters, and since some possibly escapes to the surface or is scattered through the sediments, it is reasonable to expect that only one tenth of the helium generated in the sediments reaches the helium-gas pool. Accordingly, each square mile of the gas pool as defined would require 40 to 400 cubic miles of sedimentary source material to furnish the helium. It seems improbable that the helium from such a vast volume of sediments could be concentrated in one square mile of a single reservoir.

[36] W. L. Russell, *op. cit.* (April, 1944), p. 192.

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PHOTOGRAPHY OF MEGAFOSSILS[1]

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ABSTRACT

Adequate photographic reproduction of megafossils involves geologic problems in securing an emphasis somewhat different from that desirable in most other photography. The writer has been unable to find any systematic treatise on the special problems involved. Through trial and error he has ascertained certain basic requirements for success, and has arrived at a partial solution.

Reproduction of holotypes, paratypes, and other fossils for identification requires a realism that is obtained only by reproducing an original in detail *and* elevation. These two effects, both necessary, are photographically opposed. To shoot all of a fossil for maximum detail tends to give little elevation, and *vice versa*. Moreover, this results in a muddy flatness on the one hand, or a glaring caricature on the other. Existing published plates furnish evidence that many geologists and photographers faced with the problem fail to solve it, and produce flattish images in perhaps quarter or half elevation which necessarily have an attendant degree of muddiness.

Partial solution of the basic problem has been effected by using the combination of (1) medium-contrast (detail) film, (2) very uneven lighting, and (3) sufficiently hard printing paper to force full elevation by deepening the resulting shadows to a degree which will just provide full elevation and just avoid loss of relevant detail on the major portion of the image. The total balance is a precarious one, but with most subjects is possible to attain. It partly solves the dilemma of the opposed factors detail and elevation by in effect simultaneously using moderate-contrast (detail) film for major, lighter parts, and strong contrast film for minor, darker parts of the image, thus securing both detail and full elevation.

General procedure is briefly and chronologically set forth in such a manner that even the geologist unfamiliar with photography and editorial requirements may photograph, assemble, and label material for published illustrations.

INTRODUCTION

Photographing megafossils to secure maximum clarity for identification involves geologic understanding in addition to routine photographic problems. In science, a faithful facsimile is more important than an artistic reproduction. A precise facsimile of a three-dimensional fossil necessitates a full three-dimensional effect, which, to secure, requires very uneven lighting. When photographing a well preserved equilateral shell (both halves precise duplicates) it is advisable, if necessary, to sacrifice minor duplicate parts in order to show a full three-dimensional effect for the whole. However, full elevation can usually be secured by showing major portions in full detail, and minor portions in part detail, thus partly salvaging the whole. Shells which are inequilateral occasionally prove difficult, but sufficient shadow to give the necessary full elevation can usually be shown without compromising the relevant detail.

The unguided photographer tends to try to show all parts of a shell, relevant and irrelevant, in nearly equal detail, with the result that he may use too even a lighting, which gives flat prints, and flat prints of curved surfaces inevitably include a degree of mud. Most holotypes, if reproduced flatly, and therefore mud-

[1] Manuscript received, June 23, 1945.

[2] Consulting geologist, 2062 North Sycamore Avenue. The strictly photographic procedure was worked out in collaboration with Ernest H. Quayle to whom grateful acknowledgment is made not only for invaluable aid, but also for his patience. The counsel of Walter L. Griffith aided in various ways, particularly regarding films and their characteristics.

dily, do not convey the true relation between their parts and are thus untrustworthy.

The writer has searched in vain for a systematic treatise on the photography of megafossils; if such exists it is seemingly buried where the average geologist can not find it. He has had to learn by trial and error. Recently negatives for 78 full-page faunal plates have been shot. These represent a calculation of some geological requirements involved and a partial solving of these. It is believed that the methods used are worth placing on record. An endeavor is made to present techniques in such simple outline that they can be followed by the amateur, yet so flexibly that he will be encouraged to experiment regarding his special problems.

The geologist who has the time and interest may use information given herein to photograph his fossils (if completely inexperienced he may secure an assistant familiar with routine photography, developing, and printing). If he turns the job over to a professional photographer the present paper may enable him better to convey his desires, and judge test prints, instead of just ordering some photographs and then accepting them, good or bad, as the geologist who is a stranger to faunal photography usually does.

BASIC OBJECTIVES

The purpose when photographing a fossil is to reproduce the original as accurately as possible. A score or more of problems are involved. One of these is basic, and perhaps more important and difficult to solve than all others combined. This is to secure detail *and* a full three-dimensional aspect (these two effects are more or less opposed). The problem involves chiefly correct film, lighting, focus, exposure, and printing paper.[3] Incorrect choice, and combination, of any of these factors results in some degree of mud, loss of detail, or inadequate elevation. Correct film is necessary; if incorrect, all efforts are in vain. Even lighting (incorrect) gives a two-dimensional reproduction. Uneven lighting (correct) gives three dimensions. The light should be *much* the strongest from one direction, casting *distinct* shadows. And even the best negative will give unsatisfactory results if printed on the wrong paper.

The problem, simple to state, may be found difficult to solve. There are many kinds of film, many choices of exposure, of paper, and countless lightings. Each must be correct, and all correct in combination, to secure the best results. The aggregate is a problem which even the professional never wholly solves. It is comparatively easy to secure fair, passable, "good enough" reproductions. It is

[3] For some various results, see W. P. Woodring, Ralph Stewart, and R. W. Richards, "Geology of the Kettleman Hills Oil Field, California," *U. S. Geol. Survey Prof. Paper 195* (1940). The difficult sand dollars are therein well handled, particularly Plates 45 and 46, where partly uneven lighting from the left, and properly combined photographic film and paper, give good detail and part elevation. With these well preserved equilateral subjects full elevation could be secured without relevant loss by more shadow on one hemisphere. For the inequilateral pelecypods, compare Plate 37, where uneven lighting and proper paper give good detail and a degree of elevation, with Plate 6, where flat, muddy images are seemingly the result of nearly even lighting and the choice of photographic paper, though engraving could possibly be involved.

difficult to secure exact reproductions. If the reproduction, however fair, appears less useful than the original the photographer has failed. A really good photograph of a holotype is essentially as valuable for identification as the original viewed from the particular angle reproduced. Of course, few reproductions attain this ideal On the other hand, nearly all good faunal photographs *look* better than the originals, for their approximately $\times 2$ contrast causes the images to reproduce brighter and cleaner (only) than the dull originals.

Record chart.—Figure 1 illustrates a chart for keeping a record of each trial. Such a chart will be especially valuable in early, experimental stages before the main combinations have been ascertained. And, as each plate shot tends to give somewhat different results with the same combination due to differing size, shape, and color of the fossils, the record is valuable to the last negative made. Also in later years, since the forgotten reasons for any particular former success or failure may be inferred by glancing at the chart, and the combination can accordingly be followed or changed. A blank chart of this nature can be ruled off in a few minutes with pencil and straight-edge. It should be made and be pinned on the wall beside the camera before the first negative is shot, and every relevant datum be pencilled in soon after it occurs. The writer estimates that such a chart will allow the experimental stage to be passed, as an average, in about half the time that would ensue in its absence.

Procedures which have given more or less satisfactory results when photographing megafossils (1) singly, and (2) ensemble, are presented. They may be taken as foundations, to be varied and improved according to the special problems, experience, and ingenuity of those who use them.

PART I. PHOTOGRAPHING MEGAFOSSILS SINGLY

Photographing each fossil singly, printing all to a uniform shade, cutting each reproduction out of its print with scissors, and pasting a number of these on a sheet to make up a published plate, is the usual method. It is advisable to photograph all of the fossils which are to appear on one published plate the same scale.

Cameras.—Any good camera large enough to reproduce the original natural size may be used. An 8×10-inch camera is usually necessary in ensemble photography for approximately $5\times 7\frac{1}{2}$-inch published plates, but a smaller one, say 4×5 inch, can be used for single small fossils.

Figure 2 illustrates a camera mounted on a home-made guillotine frame, with attendant lighting arrangements for three-dimensional reproduction.[4] The burnout flood illustrated is for ensemble photography, and is not used when photographing fossils singly.

Focus.—Focus is especially important when reproducing large, high objects. Perhaps the most exact method is to fully open the lens of the empty camera,

[4] Nearly all equipment shown in Figure 2 except the camera and flood globes can be improvised if necessary. However, professional equipment will be found much more convenient, and is recommended.

PLATE NO.		1	1	1	9	11	12	13	14	51	51	52	71	71	77	77
SUBJECT		SAND DOLLARS	Reshot	Reshot	SAND DOLLARS	Do.	Do.	Do.	Do.	OSTREA Large but low	Reshot	OSTREA Large, low	OSTREA Very high	Reshot	OST. Small, low	Reshot
MASTER LIGHT	GLOBE	No. 2	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.
	ELEV.	30°	25°	Do.	Do.	Do.	Do.	Do.	Do.	Do.	30°	Do.	Do.	Do.	25°	30°
	DIST.	42"	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.
Light ratio	Master / Shad. L	8/1	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	4/1	Do.	3/1	2/1	8/1	Do.
SHADOW LIGHTENER	GLOBE	No. 1	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	No. 2	Do.	Do.	Do.	No. 1	Do.
	ELEV.	50°	Do.	Do.	45°	50°	Do.	Do.	Do.	Do.	Do.	Do.	45°	40°	50°	Do.
	DIST.	90"	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	70"	60"	90"	Do.
FILM (8x10)		Pan. X	Do.	Do.	Pentagon	Pan. X	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.
APERTURE		f 32	Do.	Do.	f 45	f 32	Do.	Do.	Do.	Do.	Do.	Do.	f 45	Do.	f 32	Do.
EXPOSURE		2.4 Secs.	3.6	3.2	7.0	3.2	4.1	4.0	3.8	3.2	3.2	3.0	6.0	6.0	3.0	3.0
BURN-OUT GLOBE		No. 2	No. 1	Do.	Profess. light box	No. 1	Do.	Do.	Do.	Do.	No. 2	Do.	Do.	Do.	No. 1	Do.
WHITED?		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DEVELOPMENT		D 11 6 min.	6 min.	10 min	12 min	10 min.	10 min.	10 min.	10 min.	10 min.	10 min	10 min.	10 min.	10 m.	10 m.	10 m.
APPEARANCE OF NEGATIVE		Looks thin	Looks good	Looks good	Looks good	Looks good	Looks good	A trifle thick?	Looks good	Poor burn-out	Looks good	Looks good	Looks good	Looks good	Looks good	Looks good
APPEARANCE OF PRINTS		N. G. Flat, muddy, with halated margins	FAIR, but still some mud	O.K.	O.K.	O.K. —a trifle thin?	O.K.	O.K.	O.K.	N.G. Shads. too black, broad, and poor burn-out	O.K.	O.K.	N.G. Shads. too black	O.K.	N.G. Shads. too broad	O.K.
COMMENT		Lower master, more time, and a No. 1 in burn-out	Develop for contrast	(On No. 4 paper. Insuff. elev. on No. 3)	Do.	Do.	Do.	Do.	Do.	Try No. 2 in Shad. L.; elevate master, use No. 2 burn-out			Try a 2/1 light ratio		Elevate master	

FIG. 1.—Record chart with examples chosen to illustrate six trouble points encountered in ensemble photography for 78 page-size plates.

turn on the two photographic floods, lower the camera until the lowest part (to be shown) of the object begins to go out of focus on the ground glass, and then "mark low" with a soft pencil on the frame opposite the lower edge of the camera. Then raise the camera until the apex of the object begins to go out of focus, and "mark high." A dot about two-fifths of the range below the upper mark is then made, the camera is lowered to this, there locked, and then stopped down to the final lens opening.

Apertures.—These will vary according to the type of the camera and the height of the object photographed. With a good 8×10-inch camera an f 32 stop may give about a one-inch depth of focus, and can be used for small or flat fossils. An f 45 stop may give somewhat less than a 2-inch depth of focus, and this or a smaller stop is advisable for larger, higher fossils. These are average figures, variable according to the type of equipment.

Lighting.—Two lights are used.[5] The actual photography is done by one light—the master, the other being a mere shadow lightener which is relatively weak. In describing the position of these lights both the clock and compass systems will be used in order to convey the positions clearly. In the clock system the top of a page is 12 o'clock, with the hours accordingly arranged. In the compass system the top of a page is north.

The master light may be a No. 2 Flood (strong). It may be placed about 4 feet from the object to be photographed, at 10 or 11 o'clock, and at somewhere between 20° and 40° elevation. This corresponds with N. 60° or 30° W., with between 20° and 4c° elevation. The horizontal component is chosen to cause the light to come from the upper left corner of a page, which is standard procedure and is expected by the average eye. The elevation is chosen to cast distinct shadows, and thus provide a full three-dimensional effect. Very flat, smooth objects such as sand dollars may take a low master light of 20° to 25° elevation, because their almost microscopic protuberances require heavy shadows. Globular or other high objects take a higher master light of 30° to 40° elevation, because their height would otherwise cause too broad a shadow. In summary, the master light should come from the upper left corner of a page, and from an elevation of between 20° and 40°, according to whether the object is very flat and smooth, or very high and rugged.

The shadow lightener or second light is relatively weak, since its sole function is to lighten shadows which would otherwise be too black. It is placed approximately opposite the master light (Fig. 2), at about 45° elevation. It may be a No. 1 Flood (weak) for flattish fossils, or a No. 2 Flood (strong) for high fossils, at approximately twice the distance of the master. More shadow lighting is necessary for high, rugged objects, since the shadows to be lightened are darker. It is always to be kept in mind that the function of this weak second light is merely

[5] The curious can experiment, as the writer has done, with the tricky and dangerous system of three lights (one master and two very weak shadow lighteners) arranged in a triangle. Since the writer has thus far secured better results with two lights than with three, and with much less trouble, only the former system is described.

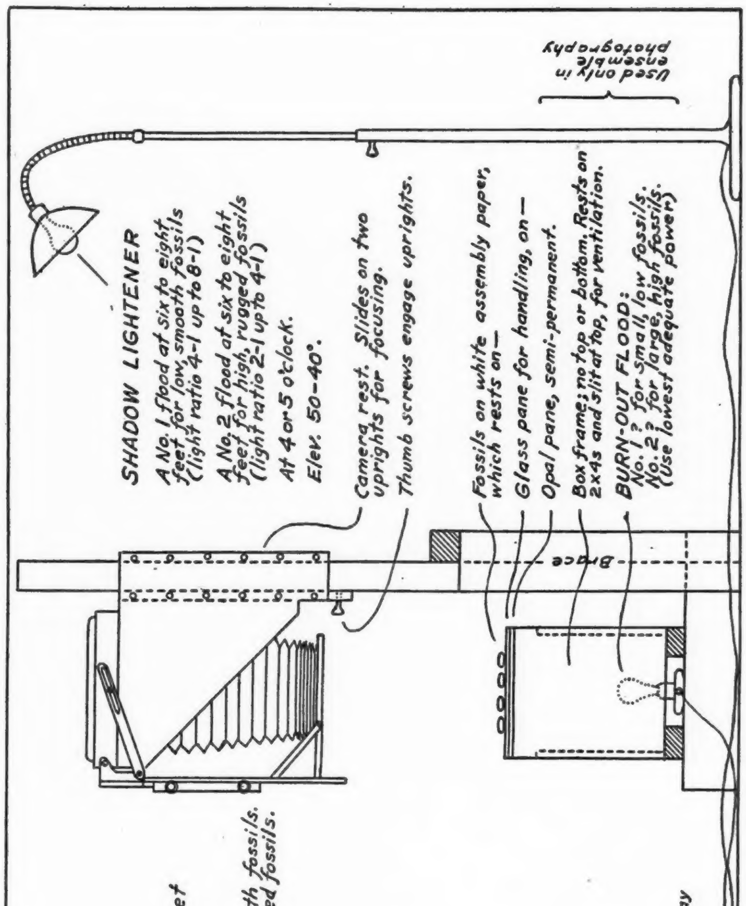

FIG. 2.—Camera mounted on home-made guillotine frame, with lighting arrangements for three-dimensional reproduction.

to lighten shadows which would otherwise be black. It must not be so strong as to kill the full three-dimensional effect, or so weak as to leave large parts of the image black. With extremely flat, smooth subjects such as sand dollars it may deliver $\frac{1}{8}$ as much light as the master light delivers; with very high, rugged, or globular subjects up to $\frac{1}{2}$ as much light as the master. With intermediate subjects the effects are in proportion. In this connection, light varies inversely as the square of the distance; the same globe twice as far away gives $\frac{1}{4}$ as much light *et cetera*. A No. 2 Flood is currently rated at about twice the power of a No. 1.

Different shapes and kinds of objects require different relations between the two lights which must be ascertained by experiment (Fig. 1). If the shadow lightener is too bright it will kill the relief and result in a somewhat flat reproduction. Strong shadows are desirable, which are dark but not completely black.

The master light produces, and controls the *shape* of, most shadows. The shadow lightener controls the *intensity* of most shadows. It is theoretically best to have the master light low, control shadows as far as possible with the shadow lightener, and elevate the master only when shadows are so broad as to obscure relevant detail.

Exposure.—Time of exposure differs greatly with different cameras, lenses, films, lightings, and stops. What can be done here is to emphasize the necessity of finding the correct exposure time. The range in time for good three-dimensional and detail faunal reproduction is rather narrow, being a fraction of the time range over which, for instance, a soft landscape or portrait may be shot. One reason for this is because the full three-dimensional effect, which is so vital, is usually obtained just before reaching underexposure, and approximately coincides with the time for the least possible mud.

The appearance of prints, not of negatives, is to be relied on (Fig. 1). The aspect of negatives tends to be deceptive. If three negatives of respectively 3, 4, and 5 seconds of exposure are held up to a light together, the best can usually be ascertained. If the three are examined separately it is difficult to rate them. If one negative will give a good print the other two will probably give mud, but which ones will give which is not always certain, as the best reproduction with fossils represents a complicated balance between several effects which is ofttimes difficult to rate in reverse shades.

When a photographer starts on megafossils it is unlikely that he will at once hit in that small exposure range which gives the best prints. And until he does he has no standard, no certain explanation why his seemingly good negatives give a degree of mud. It is here that a chart such as is shown in Figure 1 can come to his aid. If carefully kept it may soon lead him to a good print, and its record continued thereafter enables him to keep within the narrow time range. To depart more than about 30 per cent from the best exposure time tends to cause some departure from a clear, sharp reproduction. *Either* over exposure or underexposure can cause muddiness.

Experience of the writer indicates that proper time of exposure is one of the

three chief factors in avoiding mud. The other two are proper choice of film and of paper.

If the camera is hanging on a guillotine frame, and a bulb release is not available, a safe way to make the exposure without jarring the camera is to darken the room except for a distant, shaded, "way-about" light too weak to affect the film, uncover the aperture, and then plug in the flood cable for the necessary time. A stop-watch is required for accurate hand work in exposures of less than 4 or 5 seconds. A precise automatic light-switch furnishes the most accurate method.

Film.—Relatively few of the many kinds of film produced are adequate for photographing fossils. As previously mentioned, the necessary effects detail and elevation are photographically opposed, giving rise to difficulties. Detail is self-explanatory. Full elevation is secured by a use of strong shadows. In this connection, with a curved surface full elevation is not obtainable by showing light abruptly against dark, but by showing light grading to dark. It is this fact that allows us to obtain both good detail and full elevation, which are normally opposed, for we can use a detail film and reproduce the major portion of a fossil in detail, and, by very uneven lighting, reproduce minor portions in strong shadow with less detail, which will give these minor portions the effect of using contrasty, non-detail film. Of course, detail in the shadows is not full, the process being one of trading comparatively irrelevant minor loss for relevant major gain.

The writer has so far secured his best results by using moderate contrast (detail) film, and then forcing full elevation by using a sufficiently hard printing paper. If detail is not present on a negative we can not print it in. Given adequate or excessive detail on a negative, however, we can bring out different effects with different papers. By using softer or harder papers we can in effect change the film to one of less or more contrast—more detail or more elevation—if we have plenty of detail on the negative as a base.

Much of the normal detail reproduced by medium-contrast film is too fine for the unaided human eye to recognize; the eye therefore sees the finest alternations of light and dark as a muddy blur. This excess allows us to double or triple the normal contrast with hard printing papers, secure full elevation thereby, and eliminate the finer mud, all without losing seeable detail. For some reason the reverse process, that of starting with high contrast film and maintaining this contrast with soft papers, does not seem to work. The end product is not the same, appearing to be much inferior. Perhaps because hard papers appear necessary to produce adequate elevation, and these can be used only with surplus-detail film if an adequate proportion of detail is to be retained. The writer has so far had his best luck with lower medium-contrast films which, for fossils, require development for contrast. However, he has not thoroughly tested upper medium-contrast[6] films which might eliminate the necessity of development for contrast.

[6] There is apparently no systematic method in general use for rating the relative contrast of films, these being designated merely low, medium, and high. What one professional calls medium another

It thus appears best to use moderate contrast (detail) film, very uneven lighting, and then a sufficiently hard printing paper to produce the greater contrast necessary for full elevation and to eliminate the finer mud. Only properly exposed detail film can be successfully forced; such film that is overexposed or underexposed tends to print flat and muddy regardless of the paper used.

Approximately a dozen kinds of film, ranging from very low to very high contrast, have been tested on fossils and have been balanced against various papers by the writer. The very soft and very hard kinds were unsatisfactory, regardless of the treatment. Of the particular kinds tested, Panatomic X film, when developed for contrast, and printed on hard paper (usually No. 4), gave some of the more successful prints. Pentagon film furnished somewhat similar but slightly different results; it required development for contrast and No. 4 paper. It is to be emphasized that, for fossils, both of the films mentioned required development for contrast. Wider experiment by other workers may discover other and better films to add to these two found adequate for the particular requirements of fossils.

Printing paper.—The hardness or softness of the printing paper to be used is a relative matter which depends on the film. Contrasty film takes a softer paper, and film of low contrast a harder paper. Even the best faunal negatives will be disappointing if printed on the wrong paper. Too soft a paper gives a muddy, flat print, and too hard a paper a black-and-white caricature lacking detail. No paper can be specified unless the film is also specified, since the two are to be balanced one against the other.

As mentioned, the writer has thus far secured his best results by using a moderate contrast (detail) film, very uneven lighting, and then a hard printing paper to force adequate shadows and thereby elevation, and to reduce mud by eliminating surplus, unseeable detail. This reconciles the opposed factors detail and contrast by in effect combining detail and contrast film, thus eliminating respectively the muddy flatness of the former or glaring caricature of the latter, as would result if only the one potentiality were reproduced.

In general, detail films of lower medium contrast require, for fossils, at least a No. 3-plus and usually No. 4 paper. Higher-contrast film would of course take softer paper.

Developing, printing, et cetera.—Developing, printing, hypoing, washing, and glossing are all necessary and important. However, they are routine in photography, and it is with some difficulties encountered when endeavoring to reproduce types with extreme fidelity that the present paper is concerned. Accordingly, these routine matters will not be discussed at this time.

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will call low. Current manufacturers rarely give the relative contrast between even their own films. A standard method for rating contrast between 1 and 100 in several main classes each based on a standard subject color, and development would be helpful. A particular film in a class could then be assigned a basic average rating, and also a basic range for useful variations in development. The current lack of a system for even approximately rating the relative contrast of films is a serious handicap in photographic research, the worker being required to test each of several hundred unrated films.

Publishing natural size.—All published illustrations of fossils large enough to be identified with the naked eye, and not larger than a published plate, should be published natural size. The individuals of many species acquire or lose certain visible attributes between youth and maturity. And the young of some species partly recapitulate the maturity of ancestral species. Adult size is therefore a factor in identification. To publish needlessly an adult shell half or double size and assume that the matter is rectified by stating that the figure is half or double size, is an error. The mind of the reader tends to be confused; his eyes tell him one thing, the text another, and conflict persists.

The photography for publishing natural size may be done at any size desired, provided that all fossils to be shown on one published plate are photographed on the same scale. Because, if this latter is done, the aggregate, when assembled, can be marked for such reduction or magnification on the published plate as will correct the oversize or undersize of the photographs. However, when dealing with a maximum page size of $5 \times 7\frac{1}{2}$ inches, it obviously saves time, worry, and mathematics to do the photography natural size. In this connection, images within about 10 per cent of true size may be published with the caption "approximately natural size" without notably impairing identification.

PART II. PHOTOGRAPHING MEGAFOSSILS ENSEMBLE

The system here outlined for photographing fossils ensemble (all the fossils for one published plate are photographed together on one negative as the aggregate is to appear, and a print is sent in for publication) was worked out by the writer to save time, labor, and expense in large undertakings. Whether other persons have used it is unknown to him, but he has had success with it.

Ensemble photography is more complicated then the single method. It may require the geologist to be a member of the photographic crew. In any case he will usually do some contemporaneous work, since the calculation for and assembly into plates for publication are done before and as the photography progresses, not afterward. It requires that all fossils be whited. It is therefore probably not very suitable for the average professional photographer working alone, though not impossible for him if the geologist will furnish a dummy for each plate to be published.

Owing to the close crew cooperation advisable, learning to photograph fossils ensemble is not recommended where less than about half-a-dozen full plates are to be published. Once learned, however, it may be used in preference to the single method for a job as small as one published plate. Its efficacy increases with the size of the job. On a job of fifty published plates it may save half or two-thirds of the time, labor, and expense compared with the single system, and give equal or superior results. With this method it is possible to have the fossils shown on one published plate more closely related as regards shade and shadow, and to avoid the artificial aspect of margins inherent in the close-clipped single method.

Steps are described in their normal order of accomplishment.

Assembly sheets.—The geologist takes as many sheets of white, medium-thickness typewriter paper as the number of plates he expects to publish, and neatly inks on each, in strong lines, a guide rectangle *exactly* the size of the published plate as it is to appear. He numbers the sheets serially outside of each rectangle. He then arranges his fossils on the sheets as he desires them to appear on the published plates. Each fossil bears (1) a locality number, and (2) a specimen (catalog) number. It is not necessary, or even desirable, that the numbers show in the photograph. These are the sheets, with their fossils, that are to be photographed.

The dummy.—He now takes other sheets of paper, and roughly pencils on them similar rectangles and similar serial numbers. Within the rectangle on each sheet he pencils a rough outline of each fossil as it appears on an assembly sheet. (None of these things needs be done neatly, since the dummy is merely his personal duplicate, for reference, of the neat assembly sheets.) Within each outline representing a fossil he pencils (1) its locality number, (2) its specimen (catalog) number, and (3) whether it is a holotype, a paratype, or a mere specimen, *et cetera*.

The rough dummy now bears a record of the fossil arrangement on each neat assembly sheet for a published plate, and of the numbers on each fossil. If a fossil later becomes disarranged or misplaced it can thus be accurately returned to its place; or, if desired, one or all of the photographic assemblies can be torn down and be later reassembled precisely as before by referring to the dummy. Moreover, after the photography is done, all basic information necessary to write the Explanation of plates will be found on the dummy. The dummy and each finished print can then be laid side by side, be compared, and each Explanation be quickly written. (If a professional photographer can be found who has the patience to whiten fossils, which is doubtful, he might be given the dummy, the assembly sheets, and the fossils for each plate assembly in separate little boxes, and conceivably do all of the photography himself.)

Whiting fossils.—All fossils to be photographed ensemble are whited with ammonium chloride vapor. This is because the perhaps six, ten, or fifteen fossils for a published plate are usually stained different shades, and, as the camera emphasizes shades far more than does the eye, some unwhited fossils would photograph light, and others nearly black. Whiting brings them to a nearly uniform color. It sharpens the main lines and all shadows by increasing the contrast. For this reason it is sometimes also used when photographing fossils singly, especially on dark, stained, or other difficult fossils. In effect, it partly restores their original condition and shade. (It may also be used when photographing polished silver and similar articles to avoid reflected light.) A *thin* coat of whiting tends to increase the photogenic quality of drab shells several times.

Whiting with ammonium chloride vapor should be done not more than a few hours before photographing, because in humid air some whited fossils soon absorb moisture and begin to discolor. (Fossils preserved with a slick, oily, or glassy sub-

stance may begin to discolor in a few minutes.) It is therefore best to whiten a few plate assemblies at a time. Ammonium chloride may be removed by rinsing in water; if necessary, a soft brush may be used to clean out fine cracks. Do not try to whiten a fossil that is the least bit damp.

The apparatus used is very simple, consisting of a piece of glass chemistry tubing about 15 inches long and $\frac{1}{2}$ inch, or more, in diameter. One end is drawn into a point, and there a hole some $\frac{1}{16}$ inch in diameter is made. The other end is left open. About 2 teaspoons of ammonium chloride is inserted at the open end and is shaken down into the pointed end. The pointed end containing the powder is then heated (by stages to prevent cracking) in the hottest part of a strong gas jet. In one minute or less it should be possible, by blowing into the open end, to force a stream of white vapor from the pointed end.

The fossil to be whited is held on one palm, or between the fingers, on the far side of the gas jet (so the chemical can remain heating over the jet), at a distance of 1 or 2 inches from the heating end where the vapor issues. Every few minutes the point of the tube, which projects just beyond the gas flame, will begin to clog with solidified vapor. When this occurs, draw the point back into the flame, and burn and blow the plug out. One teaspoon of ammonium chloride will whiten the fossil assemblies for several plates. Add to the charge when it gets low. The larger the charge the denser the vapor.

Whiting fossils is distinctly an art. Since a thin coating accentuates lines by leaving a dark crevice flanked by white, whereas a thick coating may bridge over the very finest crevices and thus obscure lines, the idea is to use as thin a coating as is consistent with obtaining a uniform color, which need not necessarily be white. Large, coarse fossils may be made snow white. Small, delicate fossils should be coated thinly, and will seldom stand being made snow white. Large and small fossils are therefore preferably grouped in separate plates. In any case, when all fossils for a plate assembly appear to be even in color, though the color be only pinkish instead of white, stop. Conservative whiting works, on the average, for a much clearer, more faithful reproduction. The one observed danger is that of too thickly coating small, delicate fossils.

The personal habit of the writer is to circle the edge of a fossil, and then circle toward the apex. All fossils for a plate assembly are given a light coat. After comparison, a very light evening treatment. Holding the fossil near the tube point gives a thick, directed coat; holding it farther away gives a thinner, diffused coat. Blowing hard or soft, and more or less heat, are also factors. After a little practice the fossils for one published plate can be whited in three or four minutes. To touch a whited surface is to discolor it. Handle whited fossils from the bottom.

Photography.—Photography of fossils ensemble is the same as in photographing them singly (which see), except that the background is burned out from below as the plate is shot. The camera should preferably be sufficiently large to furnish a comfortable margin outside of the guide rectangle on the sheets when photographing natural size. An 8×10-inch camera is about right for published plates

of $5 \times 7\frac{1}{2}$-inches or nearly that size. If convenient, group fossils of somewhat similar height on the same plate to secure a uniform focus. If necessary to mix fossils of markedly different height the lower can be raised to the focal height of the higher by placing them on small blocks. In ensemble photography it is well to have the master light about 4 feet distant in order to minimize the difference in the amount of light received by the nearer and farther fossils.

The burn-out.—In ensemble photography, where a published plate is a precise duplicate of one photographic print as shot (except for a numbering of the component figures), it is preferable that the background be white on the print submitted for publication. This can be accomplished by having a strong light from below shine upward through an opal (milky) glass when the negative is shot.

Figure 2 illustrates one method of burning out the background. In this, the primary support for the fossils is the four walls of a box frame having no top or bottom. In home-made equipment of the writer for use with an 8×10-inch camera a box frame a trifle more than 8 inches outside width and 12 inches long is used. A guide strip is tacked along the outside of each longitudinal box wall in such a way that these guides project about $\frac{1}{4}$ inch above the top of the walls, thus allowing an 8×10-inch opal (milky) glass pane to be slid from front to back on top of the walls between the guides. It is advisable to have the box frame rest on criss-crossed two-by-fours, and have at least the upper one inch of the end walls cut out to provide circulation of air. Otherwise, intense heat from the burn-out flood may crack the glass pane during long tests for fossil position.

A flood globe is set upright at the center and near the bottom of the box frame, and is connected through a three-way plug with the two photographic floods so that the three floods can be turned on and off either separately or simultaneously (Fig. 2). The opal (milky) glass pane used to diffuse the light from below always remains on the box frame.

It is important that the burn-out flood be of the lowest power consistent with eliminating shadows cast on the background. This is because light from below tends to be reflected to the upper surface of the fossils, particularly at their margins. Marked halation caused by too strong a burn-out causes the reproduced margin of fossils to be faint and blurred. This is particularly true with small fossils; in fact, very small fossils may have to be photographed singly (with no burn-out) and be pasted in. Fossils one-inch or more in diameter will usually stand a proper burning out from below. Use the least burn-out necessary; that is, a No. 2 (strong) flood only when a No. 1 (weaker) flood has been demonstrated to be inadequate.

Professional light-boxes are available which have many small, weak globes, but those tested, though slightly better than a single flood, have not overcome the danger of halated margins. It seems probable that lighting engineers could design burn-out apparatus which could burn out for even small fossils without marked halation. Apparatus which will eliminate the danger of halated margins is the one

thing necessary to make ensemble photography superior to the single, cut-and-paste method.

Routine.—To prepare for photography a white assembly sheet, on which, as described, a strong guide rectangle the exact size of the plate to be published has previously been neatly ruled in ink, is laid on top of an 8×10-inch foundation pane of glass. It is well to have several glass foundation panes so that several plates may be made up at a time. The whited fossils are arranged on this in their proper position by referring to the dummy, which should be followed precisely. Several such plates may be made up at one time at a table.

To photograph, a fossil assembly resting on an assembly sheet, which in turn rests on a glass pane, is carried to the camera and is slid on top of the semipermanent opal (milky) glass foundation. There is now on top of the box frame (1) a semi-permanent opal glass pane, on which rests (2) another glass pane, on which rests (3) the white assembly sheet with its arranged fossils. The burn-out flood is now plugged in alone, and the photographer looks down through the empty camera with lens opened wide and directs an assistant to slide the white assembly sheet a trifle in whatever direction is necessary to center its guide rectangle. The burn-out flood is then disconnected, the two photographic floods are plugged in, and the thumb screws locking the camera to the guillotine frame are loosened. The photographer focuses, lowering the camera for the assistant to "mark low," raising it to "mark high," and then lowers it about two-fifths to the exact focus position, guided by the assistant who locks the camera there.

The photographer stops down the lens to the desired aperture, while the assistant connects the burn-out flood to the two photographic floods. The room is then darkened except for a distant, shaded "way-about" light too weak to affect the film. The photographer now inserts a film in the camera, takes up a stop-watch in one hand and a master plug in the other, and makes the exposure by plugging in and out. Or by using a photographer's bulb. Or with an automatic light-switch if so equipped. All relevant data are then recorded on the chart (Fig. 1).

During the experimental stage it is advisable to develop and print each negative when shot in order to estimate how the succeeding one can be improved, since the best combination of the many component factors may require repeated changes. After a satisfactory print has been obtained, and the reason for this ascertained from the record on the chart, it may be possible to photograph and develop steadily all one day and print all the next day—as long as the general size, shape, and other attributes of the fossils dealt with remain similar. Therefore, photograph similar fossils before going on to others.

At each marked change to a new size and shape of fossil a test negative is advisable, since the elevation of the master light, distance of the shadow lightener, strength for burn-out, and the exposure, may one or all have to be changed (Fig. 1). After a little experience from 20 to 30 assemblies (published plates) can be whited and shot in one day by a three-man team in which two men photograph

and one man develops. It is well for the photographer to examine each negative, when developed, to be sure that he is still on the right track. If subsequent printing reveals an occasional unsatisfactory negative this can be later reshot with corrections.

Photographing fossils ensemble as described will presumably sound complicated to the amateur, but not to a professional photographer. As mentioned, to photograph fossils singly is probably preferable for the uninitiated when only a few published plates are concerned. On the other hand, when once learned ensemble photography is not difficult to execute, can give equal or superior quality, and where scores of published plates reproducing hundreds of fossils are involved can cut the total time, labor, and expense to a fraction of that required in the single fossil, print-to-similar-shade, cut-sand-paste method.

Grief.—The experienced photographer of fossils has easy sailing, but the amateur tends to encounter trouble that puzzles him because he may not know which of several component factors are causing it. The amateur can solve some of his problems by presenting them to a good professional photographer—but not all of his problems. Many professional photographers fail when they first attack the special problem of fossils; partly because they may try to present all of a fossil in detail and simultaneously secure adequate elevation, a theoretical impossibility as adequate elevation requires strong shadows that must dim some detail on a minor portion of the fossil.

It may be necessary for the amateur photographer to experiment repeatedly, keeping a careful record of all factors. When he secures his first really good print the worst of his trouble should be over—if the chart contains a record of exactly how he got it.

Some troubles and their possible causes are here listed. In this connection, when a negative that appears good gives an unsatisfactory print it is advisable to test a harder or softer printing paper on it. Not only because wrong paper is a major cause of grief and the easiest one to rectify, but also because comparing the better and worse prints so obtained may provide a clue to other troubles.

Trouble	*Possible Cause*
Muddy	Film lacks contrast, or, more probably, Negative over- or under-exposed, or Printing paper too soft.
Flat	Master light too high, or Shadow lightener too strong, or Negative over- or under-exposed, or Printing paper too soft.
Poor detail	Film too contrasty, or Negative over- or under-exposed, or Printing paper too hard.
Good, except shadows too black	Shadow lightener too weak.
Good, except shadows too broad	Master light too low.
Dim margins	Burn-out too strong.
Shadows on background	Burn-out too weak.

Mud, the most common and difficult trouble, means that lines and shadows do not stand out against the body; that is, not enough contrast. The opposite condition, poor detail, means that major lines and shadows are present, but finer ones are absent; that is, too much contrast.

Dodging prints.—A goodly proportion of prints of fossil groups shot ensemble may require some dodging (printing dark and light images to a similar shade) to secure an even print, because the camera exaggerates differences in shade which are imperceptible to the eye when whiting, and also because the master light is a little nearer to some fossils than to others. With careful, fairly even whiting perhaps about 50 per cent of ensemble negatives may be printed without dodging. Perhaps about 35 per cent may show some fossils lighter or darker than others and require minor dodging. Perhaps about 15 per cent may require complicated dodging. If the master light is placed 4 or more feet from the center of the fossils when shooting a negative the amount of dodging will depend chiefly on the evenness of whiting.

Dodging requires that prints be made by hand beneath an overhead light. A test print, undodged, is first made, the photographer estimating the exposure required. The developed print is examined in the hypo, and corrections are estimated. If no dodging is required further procedure is merely one of estimating for correct time, and the second print may be satisfactory. If dodging is required total exposure time is predicated on the basis of the lightest fossil image, and others are dodged (given less light) accordingly. To illustrate: if there are four fossil images on a negative, the test print may indicate that the two lightest on this print will require 20 seconds exposure. This, then, is the total time. A third fossil image, darker on the test print, is estimated at 18 seconds, and the fourth, still darker, is estimated at 16.

Persons who do not have an automatic light-switch had best dodge by the subtraction method, as follows. The negative and the underlying printing paper are assembled in faint light, and two pieces of black paper are placed one over each of the images on the negative requiring respectively 18 and 16 seconds. A stop-watch is started simultaneously with the printing light. At two seconds the covering paper is jerked from the image requiring 18 seconds, and at 4 seconds from the image requiring 16. All images thereafter receive light until the end of the 20 seconds total time, when the light is turned off. The even test time of 20 seconds which resulted in an uneven print has now been changed on this second trial to uneven timing (20-20-18-16 seconds) which gives a more even print. This second print may be satisfactory; if not, another ratio is calculated. If the paper prints too fast for good dodging increase the distance to the printing light to secure more time. Because dry, glossed prints in bright light look different from wet ones in hypo, it is well to make three prints, one supposedly correct, one a little lighter, and one a little darker. The best can later be chosen.

Professional photographers or others who have an automatic light-switch of precise quality will find it easier and more accurate to use the addition method.

In this, all fossil images are first exposed for the minimum time, if we take the mentioned example, 16 seconds. The fossil image requiring that amount of time is then covered with black paper, the automatic timer is set for two seconds, and the other three images receive this additional exposure. The image requiring 18 seconds is now also covered, the timer button is again pressed, and the remaining two fossils receive another two seconds. By addition, there has now been secured (in reverse method) the 20-20-18-16 ratio of the subtraction example. Dodging with a good automatic light-switch is not only more accurate than without it, but can be done leisurely, without the acrobatics otherwise necessary in complicated cases.

If part of any one fossil image prints well and another part nearly black (too heavy a shadow), the part that is too dark may be dodged by passing the fingers over that part a calculated number of times when printing; movement is necessary to avoid a sharp line between shades. If all fossils have shadows too black, reshoot the negative with a stronger shadow lightener; if shadows are too light, use a weaker shadow lightener. If an occasional negative is too complicated to dodge, as where a score of small fossils reproduce in several shades, make three or four undodged prints, from light to dark, select single images of similar shade from these, and cut and paste as in the single method. However, the writer was forced to do this for only one plate in a 78-plate series. If it is desired to show two views of one fossil on the *same* published plate, leave a space vacant when shooting the ensemble, shoot the other view singly, cut it out, and paste it in.

Numbering and scaling prints.—When all prints have been made, they are all (1) checked against the dummy. (2) The number for each published plate is rewritten, if changed, in the upper right corner outside of the guide rectangle. (3) The name of the author is written in the upper left-hand corner outside of the rectangle, for identification. (4) The length for the published plate is then written along the right edge of the print outside of the guide rectangle. (The engraver should be advised, through the editor, to tool out the guide rectangle when its usefulness is past.)

For natural size specify the length of the guide rectangle *as originally drawn*, regardless of its length on the print, since such will return the published images to approximately natural size regardless of how large or small they were photographed. This refers to small fossils and very flat large fossils. Large, high fossils will have photographed a little large relative to the guide rectangle, due to a cone effect; these may be designated "approximately" natural size, or, with fossils of uniform size, the amount of distortion may be measured, the marked length for for the published plate be slightly decreased, and true natural size thus be shown. An illustration within 10 per cent of true may reasonably be labelled "approximately" natural size. Larger discrepancies should be labelled 1.2, $\frac{7}{8}$, $\frac{8}{7}$, *et cetera* of natural size.

A reference number is drafted near the edge of each fossil image within the guide rectangle. This completes the print for a published plate. Since the print

and its dummy now supply all necessary information, the explanation for each plate can be easily written.

It is advisable, where material for page-size plates is concerned, to mount each print (assembled or ensemble) on a sheet of cardboard by means of rubber cement, to prevent irksome curling and breakage during editorial and other handling. A sheet of tissue paper cemented by one edge to the left margin of the cardboard mounting tends to prevent scratches during the same ordeal.

ENGRAVING AND PRINTING

Under this head are included all methods for transferring the image on a photographic print to a published plate. Photography, engraving, and printing are interdependent, and each influences the others as regards the final effect. Good engravers and printers accomplish wonders in transferring the image accurately. Some, however, have a tendency to produce an image lighter than the photographic print. This reduces shadow, thus partly kills elevation, and by diminishing contrast gives a degree of mud in the published plate. Just as an engraver can not produce a good plate from a poor photograph, it is useless for a photographer to make a range of prints and select a good dark one showing excellent shadow, contrast, and detail, if the engraver or printer reproduces it light and thus reduces it to the status of a discarded flat print lacking contrast. Of course, a reproduction darker than the print is also undesirable, but the writer has personally never observed an instance of this; for reasons unknown to him the departure seems to be nearly always toward a lighter shade. In engraving and printing faunal plates it is important to reproduce the same shade, neither lighter or darker, of the photographic print furnished.

Published plates in black-and-white on slick paper are considerably more distinct and useful than in brown-and-white or on dull paper. It is difficult to secure full elevation with brown shades or a dull surface, which flatten and dim the image.

CONCLUSION

This article has been written to save geologists the time, labor, and worry expended by the writer in working out, by trial and error, methods for faithfully reproducing fossils. Methods herein described are primitive, and are subject to large improvement. It is hoped that all concerned will endeavor to improve on them.

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RESEARCH NOTES

RESEARCH COMMITTEE PROGRAM[1]

S. W. LOWMAN[2]
Houston, Texas

The present rapid expansion of industrial research and development indicates that extensive funds may be available for cooperative research.[3] The faster we draw on our store of knowledge the sooner we reach the Mother Hubbard stage unless we restock our shelves. However, "the sizeable funds which may be available for (cooperative) research will probably not come out of hiding until a well thought-out, comprehensive program of research has been developed and recommended by those qualified to speak with authority. In the field of petroleum geology the Association is certainly qualified to speak with authority and should speak."[4]

Within the Association it is clearly the responsibility of the research committee to make the analysis on which such a program should be based. There is no thought that this year's committee will produce "the answer" but there are many sign-posts which help us to start in the right direction. For instance, last year's executive committee took the stand that the Association should sponsor no research projects until a survey had been made of the field of research in petroleum geology and allied sciences. This year's executive committee adopted a resolution commending the analytical approach to the problem of A.A.P.G. participation in research and suggested three steps which are closely similar to those shown in the Agenda. Several reports of the Division of Geology and Geography of the National Research Council show a strong trend toward analysis of our research needs. One of these[5] contains the following statements, which are quoted only in part.

Paul Bartsch: "While all problems that make for advance in science are laudable, many or most of the efforts appear to result in heaving another brick on the already huge accumulation of other odds and ends of bricks that will probably remain on the waste pile forever."

Kenneth C. Heald: "I would like to see a real attempt to appraise the outstanding needs in the way of geologic research. It does not seem to me that this is a project that can be handled hastily. It will require a good deal of thought, and there should be careful consideration and discussion by men who know research and who are familiar with the various types of geologic work that may be benefited by an attack adequately financed and directed."

Rudolf Ruedemann: "It seems to me that too many divergent and scattered researches

[1] Manuscript received, September 21, 1945.

[2] Chairman, research committee. Shell Oil Company, Inc.

[3] Research, as used in this program, includes "scientific research," "background research," and "industrial research and development," as defined in "Report of the Committee on Science and the Public Welfare," Isaiah Bowman, chairman, in *Science—the Endless Frontier: Report to the President on a Program for Postwar Scientific Research*, by Vannevar Bush, Director of Office of Scientific Research and Development (July, 1945), pp. 75-77.

[4] Ira H. Cram, "Report of President," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 5 (May, 1945), p. 582.

[5] *Suggestions Concerning Desirable Lines of Research in the Fields of Geology and Geography*, edited by Edson S. Bastin, Carl O. Dunbar, and Robert S. Platt, National Research Council, Division of Geology and Geography (December, 1936).

lead to a waste of effort when enough data have been accumulated to organize further research."

C. E. Weaver: "My feeling is that a very large amount of research is carried on at considerable expense and effort which would be far more effective in the advancement of geologic science if it is fitted into some plan of coordination."

A recent symposium on industrial research (*The Future of Industrial Research*, Standard Oil Development Co., New York, 1945) has added impetus to organized research by reporting on different aspects of the success achieved by scientific teams in industrial laboratories, and other laboratories dedicated to industry, during the last twenty-five years.

Following these and many similar leads, the program outlined in the following paragraphs has been formulated for this year's research committee.

OBJECTIVES

1. To complete a reconnaissance survey of research in petroleum geology and allied sciences with explicit reference to exploration.

2. To formulate a comprehensive research program which the American Association of Petroleum Geologists may adopt as its recommendation for that research most needed to improve our ability to find oil.

AGENDA

1. SURVEY THE FIELD

a. What do we know and what important advances have been made in recent years, the results of which may not yet have been fully assimilated? *b.* How is our knowledge being applied to finding oil? *c.* What obvious gaps are there in our knowledge or its application? *d.* What research is under way now or is already projected to fill these gaps? *e.* What research facilities and personnel are available for cooperative research in or related to petroleum geology?

2. ANALYZE AND EVALUATE

a. Research projects already terminated, in order to determine whether any of them should be re-established; *b.* Research projects now under way or proposed, to determine their relative value and urgency to exploration and the desirability, from our point of view, of expansion or revision; *c.* Need for additional research.

3. TAKE APPROPRIATE ACTION

a. Formulate a comprehensive program as set forth under "objectives." *b.* Divide the program into specific projects and rate them both as to their relative urgency and as to their applied (short-range) or fundamental (long-range) character. *c.* Recommend possible disposition of individual projects or groups of projects as indicated by the survey under 1-*e* or recommend further consideration by the appropriate A.A.P.G. committee or committees.

SCHEDULE

January 15. Progress reports of subcommittees on Agenda 1 and 2.

(These reports will be duplicated for distribution to members and consultants of the research committee and to members of the executive committee. This interchange of evaluated data will promote coordination of the final reports of the subcommittees and will serve as a basis for preliminary work on the joint report of the research committee. They will also serve to keep the executive committee advised of the progress of the investigation.)

March 1. Preliminary joint report of the research committee.

April 1± Final reports and recommendation of the research committee following round-table discussions at the annual meeting.

ORGANIZATION

S. W. Lowman, *Chairman*
E. R. Atwill, *vice-chairman*, western United States
W. P. Haynes, *vice-chairman*, eastern United States

SUBCOMMITTEES

Stratigraphy and Sedimentation
R. K. DeFord
G. M. Kay*
W. C. Krumbein
W. W. Rubey
W. H. Twenhofel
and consultants

Tectonics
C. I. Alexander
A. H. Bell
P. B. King*
R. A. Liddle
W. T. Thom, Jr.
and consultants

Reservoir Fluids
R. F. Beers
W. R. Berger
P. E. Fitzgerald
G. C. Gester*
R. N. Kolm
G. B. Moody
F. M. Van Tuyl
and consultants

Research Facilities
D. P. Olcott
and consultants

Geophysics and Geochemistry
J. A. Sharpe*
and consultants

Production Engineering
S. E. Buckley*
and consultants

Discovery Thinking
I. H. Cram
A. I. Levorsen
and consultants

Project Areas
M. A. Hanna*
and consultants

* Chairman

CONSULTANTS

The membership of the research committee is not sufficiently large to conduct a survey on the scale proposed for this year. Furthermore, some of the subjects proposed for the investigation are represented on the committee by only one or two members whereas several are needed for each subject. To fill this need the president will appoint consultants, selected by the chairmen of the subcommittees, the appointment being for the current Association year. Consultants need not be members of the Association, although we presumably have more claim to the interest and active assistance of Association members. However, if a specialist in some allied field were sufficiently interested to help us make this analytical survey we would, of course, welcome such assistance.

SUGGESTED SCOPE OF SUBCOMMITTEE INVESTIGATION

Stratigraphy and Sedimentation. a. Sedimentation and related phases of oceanography; *b.* Diagenesis with particular reference to geophysical and geochemical processes; *c.* Sedimentary petrology and mineralogy; *d.* Paleontology, paleoecology and related phases of biology—especially marine ecology and related phases of oceanography; *e.* Theoretical stratigraphy, including theory of correlating dissimilarities, theory of matching similar sequences, cyclical and oscillatory sequences of bio- and litho-facies, contemporaneous movement, unconformities.

Tectonics. A. Kinematic and geometric measurement of structural features: *a.* Intermontane regions such as the Pacific Coast, *b.* Epicontinental regions such as central North America, and *c.* Geosynclinal regions such as the Gulf Coast.

B. Theoretical and Experimental: *a.* Mechanics of deformation, *b.* Scale models, and *c.* Soil mechanics.

Reservoir Fluids (Hydrocarbons and Formation Water). A. Observed relationships: *a.* Stratigraphic and structural relationships, *b.* Physical and chemical relationships, and *c.* Interrelationships of *a* and *b.*

B. Theoretical and Experimental: *a.* Origin, *b.* Migration and accumulation, *c.* Diagenesis, and *d.* Regional reservoir behavior.

Geophysics and Geochemistry. It is proposed that this subcommittee should consider the basic aspects of the subjects. This will produce overlap with other subcommittees

which, however, would be reduced by emphasizing those phases of the subjects which are being applied or give promise of application to exploration by means of new or improved "geophysical" and "geochemical" methods or techniques.

Production Engineering. This subcommittee will review those portions of research and research needs in petroleum engineering which overlap some phases of exploration research. It will advise other subcommittees of advances recently made and researches now in progress in production engineering which are closely related to their fields. It will also advise production engineers of those portions of our research program which might be of direct interest to them so that they would have the opportunity to suggest useful additions or modifications.

Discovery Thinking. This subcommittee cuts across the first five and therefore produces duplication, but it also produces a check. It is designed to analyze planning and selection of method just as the other subcommittees analyze experience in their respective fields. It is my thought that we can and should analyze judgment just as critically as we do any other specialized field. In a sense, this is a steering committee which should produce an additional objective background against which to judge the value and relative urgency to exploration of the results of the other subcommittees.

Project Areas. This is also a steering committee, intended to furnish a geographic background for locating and grouping projects recommended by other subcommittees. By analyzing the features of the major regions of the United States which recommend them as natural laboratories of geological research we should tend to reduce overemphasis on one region that might develop as a result of temporary causes.

Research Facilities. There are hundreds of institutions in the United States alone which are engaged in scientific research. The subcommittee on Research Facilities has for its objective the organization and initiation of a survey designed to discover which of these institutions are doing work that we are interested in, what they are doing, and what facilities and personnel they have which might be allocated to additional research projects which we may recommend.

OMISSIONS

Notable omissions from the list of special subjects to be considered by subcommittees include *a.* Surface and subsurface methods (including aerial photography), *b.* Igneous and metamorphic (basement, extrusives and intrusives, geologic time), *c.* Regions outside the United States (particularly the western hemisphere). All three deserve a place in the general framework and they could be included as special assignments or one-man subcommittees with consultants if it seems to be desirable to do so. However, there are probably many other omissions, the resources of the research committee are limited, and we have to draw the line somewhere.

RECONNAISSANCE CHARACTER OF THE SURVEY

It is obvious that we can not hope to do the work described in this program in any but a broadly reconnaissance manner. Two or three round-table discussions by groups of experts should skim much of the cream. A reconnaissance survey may be all that we need at the present time and, if it is not, it should serve as a basis for finding out what more is needed.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

BASIC ENGLISH FOR GEOLOGY

REVIEW BY BURTON WALLACE COLLINS[1]
Auckland, New Zealand

Basic for Geology, by P. M. Rossiter. Kegan Paul, Trench, Trubner and Co., Ltd., London (1937). 164 pp. Price, 2s. 6d. (70 cents).
Basic for Science, by C. K. Ogden. *Ibid.* (1942). 314 pp. Same price.
Basic English and Its Uses, by I. A. Richards. *Ibid.* (1943). 127 pp.

> Without canned food, modern metallurgy, and oil, there could be no global war. These new inventions have not been balanced by equal developments in the means of mental transport—and thereby in the spreading of the common truths which would make antagonism and disloyalty harder to cultivate. But these other discoveries are ready to hand—as these pages will attempt to show.

This quotation from the preface to Dr. Richards' book puts the general case for an international language in a nutshell—that an international medium of communication would do much to promote international understanding and to prevent future wars. His book is a short, readable account (written in forceful "unlimited" English), which, in his own words, presents

> first some of the reasons for believing that a simplified form of English is the most practicable common language, and with them, the grounds for doubting whether any artificial language yet devised or imagined could do the same work as adequately. I then describe the form of English which I believe most nearly meets the need, its relationship to unlimited English, and how it has been disengaged from the parent language. I then discuss the teaching of this simplified English. . . . Finally I show how this simplified form of English . . . may be used to improve and enrich understanding for those of us who are born to the langugae of Shakespeare and Milton.

In an appendix is given an annotated selection of books on or in Basic English.

* * *

The readers of this *Bulletin*, however, whether familiar with Basic or not, will probably be more interested in the other two books listed. There can be little (if any) opposition to the statement that science in general, and geology in particular, would benefit greatly from the use of an international language. Fortunately, work done in America, Great Britain, and the Dominions is already published in a common language and is available to all fellow-workers in those countries. To use a topical analogy, two of the "big three" use a common tongue—but Marshal Stalin needs an interpreter. It is interesting to speculate as to how much we lose through not having the work of Russian geologists (and biologists, chemists, physiologists, *et al.*) readily available to us. And no doubt the loss is mutual. Probably there is much unnecessary duplication of effort. Multiply the disadvantages by the number of languages in which scientific work is published (including French, Dutch, Spanish, the Scandinavian languages, German, Italian, Chinese, and Japanese) and the need for an international scientific language—especially for abstracts of papers presenting original work—is all too obvious.

One could not do better than quote from the first page of Mr. Ogden's book (itself written entirely in Basic English):

> Nowhere is the need for an international language clearer or more serious than in the field of sci-

[1] P.O. Box 10, Auckland CI, New Zealand. Manuscript received, June 25, 1945.

ence. It is highly important for the worker in science to be able to keep in touch not only with the great discoveries but with the little additions to the store of knowledge made month by month in one country or another. On the other hand, in no group is there so general a desire to put the record of independent work before the widest possible public of experts. Comparison of observations, tests, and theories is the very breath of science.

Having work printed in a number of other languages is a very dear, slow, and incomplete way of making science international. So is the learning of languages by men of science themselves.

The Basic system is described in the first part of this book, and the following quotations will serve to indicate its main features to those meeting it for the first time:

Basic is English made simple by limiting the number of words to 850, and the rules for managing them to the smallest number necessary for the clear statement of ideas as conditioned by the structure of the language. That with so small a word-list and so little apparatus it is possible to say anything desired for the purposes of everyday existence is the outcome of the . . . system of word-selection, together with the great step—a step based on a natural tendency of English, and possible in no other European language of the present day—of cutting out "verbs." . . .

In writings designed for those trained in science, the word-list is increased by another 100 words covering the general language of science, and 50 more for the needs of any special branch. . . .

As well as the thousand words referred to, Basic for science makes use of a great number of words which are already "international"—that is, common with only unimportant changes of form, to at least the six chief languages of Europe (English, French, German, Spanish, Italian, and Russian). For example, to quote Ogden again:

As a start . . . there are a certain number of units about which there is no doubt—the Latin names used in the grouping of insects, plants, and animals; the signs of Physics, Chemistry, and Mathematics; the naming-system of Petrology, and a great part of those of Geology and Palaeontology; weights and measures in the Metric System.

The greater part of *Basic for Science,* consists, however, of translations into Basic of extracts from scientific books and articles. The tentative special lists for the following fields are also included: General Science (100 words), Mathematics-Mechanics (50 words), Geology (50), Biology (50), Physics-Chemistry (50). The specimen translations form a conclusive practical demonstration of the value and workability of the Basic system for science.

The book concludes with a few specimen pages from the projected *Basic Science Dictionary* (defining scientific terms in Basic), a list of all the special Basic science words defined in ordinary Basic, and a selection of about 600 of the commonest "international" science words.

Basic for Science is a revised and enlarged (in great part rewritten) edition of *Basic English Applied* (*Science*) by the same author, published in 1931.

* * *

Mrs. Rossiter's book goes into the question of an international language for geology in more detail, discusses the choice of the 50 special Basic words for geology, includes five specimen translations, and concludes with several useful word-lists (in particular, one of about 300 international geology words). The passages for translation have been chosen to cover various phases of geology; the translations themselves are very readable, quite smooth in style, and do not appear to have lost in accuracy. They have been taken from the following works: *Chapters on the Geology of Scotland,* by B. N. Peach and J. Horne (petrology and structural geology); *Graptolite Faunas of the British Isles: A Study in Evolution,* by G. L. Elles (paleontology); *The Origin of Igneous Rocks,* by Arthur Holmes (petrology); *The Natural History of Ice and Snow,* by A. E. Tutton (glaciology; and *On the Processes of Destruction Now at Work,* by Archibald Geikie (geomorphology).

An example chosen at random gives some idea of the effectiveness of Basic English for the purposes of geology:

There have been some general attempts at grouping the Graptoloidea, but up to now very little

detailed work on their evolution has been done. The first discussion of the possible phylogeny of the Dichograptidae was by Marr and Nicholson and their idea was worked out on a greater scale by the writer and later by Ruedemann; however, only the development in one line of one family was worked out by these writers and nothing after the *Didymograptus* stage was attempted. In addition, Wimans has made the statement that *Monograptus* has its origin in more than one line of evolution, because it would seem to have come from *Diplograptus* and *Climacograptus* forms, but he gives no details.

This work, of which the chief results are given here, has been done to make clear, so far as possible, the other lines of development which the structure has taken and the geological times of the more important and different stages, because these would give material of great use in getting the zones in Stratigraphy fixed.

Four chief lines of evolution may be seen in the Graptoloidea—

1. Change in direction of growth of the rhabdosome.
2. Branching becoming more simple.
3. Changes giving a more complex form of theca.
4. The wall of the chitin covering becoming thick in certain special areas.

(From G. L. Elles, *op. cit.*, *Proc. Geol. Assoc.*, 1922)

* * *

The following word-lists may be of interest to those who think that Basic is worth further consideration.

Basic Special List for Geology (as given in Ogden, 1942)

birefringence	*flow	overlap
cast	foliation	plain
*cave	fracture	scarp
clay	glacier	schist
cleavage	gravel	shale
contour	ground	shore
*desert	hill	sill
dip	inclusion	slate
*drift	intercept	strike
dyke	interpenetration	texture
*erosion	*intrusion	twin
*eruption	lake	unconformity
extinction	limestone	valley
*fan	mud	
fault	ore	*accessory
flint	outcrop	igneous
flood	outlier	sedimentary

Those marked * were not in the original list published by Rossiter in 1937. Their places were taken by the following:

age, ash, section, shear, thickness, thrust (now included in the General Science List of 100 words), *block, vein, fossil* (now considered to be international—"block" only in its special geological sense)

Special Uses of (Ordinary) Basic Words in Geology (Rossiter, 1937)

arch; rock-arch	guide-fossil
basin	neck
bedding; current-bedded; false-bedding	outwash; outwash-plain
coal-ball	pothole
complex; igneous complex	slip; earth-slip; land-slip; snow-slip
country-rock	wall; foot-wall; hanging-wall
edge-angle	water-table
fold; over-fold; under-fold	weathering
grain	window

Other Ordinary Basic Words Useful in Geology (selected by the reviewer)

band	island	plane	snow
chalk	level	pocket	stone
copper	line	pump	structure
earth	map	rain	system
field	metal	river	tin
gold	mine	salt	wave
hammer	mountain	sand	acid
hole	nose	sea	elastic
ice	oil	silver	parallel
iron	pipe	slope	regular

Some Words in the Basic General Science List Useful in Geology
(selected by the reviewer)

area	layer	solution
column	nucleus	specimen
deposit	origin	strain
disturbance	rigidity	stress
environment	rock	supply
impurity	section	surface
joint	shell	

Some International Science Words (selected by the reviewer)

agent	method	symbol
anomaly	ocean	symmetry
classification	order	temperature
composition	petroleum	transverse
correlation	plan	type
crystal	primitive	universal
diagram	principle	variety
erosion	real	vertical
evolution	result	volume
fossil	sediment	X-ray
genus	series	zero
meteoric	superposition	zone

Some International Geology Words (selected by the reveiwer from Rossiter, 1937)

accessory	dislocation	orogenic
alluvial	dune	peneplain
anticline	dynamic	period
atoll	eruption	phase
basic	facies	plateau
breccia	fumarole	plutonic
caldera	gangue	reef
clastic	geyser	relief
concretion	glacial	secondary
contact	insequent	stock
continent	intrusion	strata
coral	lava	syncline
corrasion	littoral	tectonic
crater	magma	terrace
cycle	metamorphic	terrestrial
denudation	mineral	transgression
detritus	moraine	tuff
diastrophism	oolite	volcano

It must be emphasized that, with the exception of the first, none of these lists is exhaustive. In the last two, in particular, are included only a few of the available international words. Numerous names of minerals and rocks, and many recently coined terms (especially those with classical roots) are, for instance, also international. It will be realized, therefore, that the use of Basic English does not impose too great a strain on the scientific writer in regard to vocabulary. It will be found that where the English writer must be most careful when writing in Basic is in the matter of style—especially in the elimination of most verbs. "Simplify," for example, becomes "make simple," and "classify," "put into groups." It is important to remember that most of the international words may be used only in the form of the noun in Basic—a few as adjectives, but none as verbs in the ordinary sense.

Finally, it should be mentioned that the sponsors of Basic ("British American Scientific International Commercial" is their slogan) state that they welcome criticism and advice. Mrs. Rossiter, for instance, states in regard to her "List of International Words in Geology":

There is no suggestion that the list is complete and it is possible that some of the words are not as

widely used as seemed probable at first view. The writer would be very pleased to have any notes, suggestions or discussions about these words and any possible additions to the list. These may be sent to

The Orthological Institute,
10, King's Parade,
Cambridge,
England.

THE STORY OF THE GREAT GEOLOGISTS, BY CARROLL LANE FENTON AND MILDRED ADAMS FENTON

REVIEW BY A. RODGER DENISON[1]
Tulsa, Oklahoma

The Story of the Great Geologists, by Carroll Lane Fenton and Mildred Adams Fenton. Doubleday, Doran and Company, Inc., Garden City, New York (1945). 286 pp., 20 half tones, 27 line cuts, 6 pp. references, 7 pp. index. Price, $3.50.

The collaborators in this volume are both connected with Rutgers University, Mr. Fenton as science editor and Mrs. Fenton as curator of the Geological Museum. It is the third work of the joint authorship, others being *The Rock Book* and *Mountains*. This book relates the history of geology—the science—from Ancient Greece to modern times with the very minimum of technical language. Recognizing that the story of such a development is " . . . long, diverse [and] complex," the authors have elected a new approach, " . . . to tell it [the story] through the lives of men—men who in their diverse ways loved our planet and labored to make it known. . . . to write about men who dealt with the earth as a whole or with features of such magnitude that they influence all geologic thought." The truly biographical side is stressed "For the men of Science are human . . . no man is transformed into a mental machine by mounting to a professorial chair, by writing a learned treatise, or by joining a government survey."

The authors recognize the evolution of the science in the following words—"Geology once was compact, simple, unified; a body of knowledge about our earth as seen by man's unaided eye. . . . today the science has become so much divided that men who work in one field may neither know or understand those who specialize in another." This evolution was brought about by, " . . . a band of clergymen, teachers, officials, philosophers and men of leisure who turned . . . scattered, poorly organized observations into a science of the earth."

While the foundations for the science were laid in Europe it was in the new world that "it reaches its full intensity . . . for there the men of rocks became pioneers, journeying into the unknown . . . sharing the glory of voyagers and frontiersmen . . . set[ting] a precedent for bold exploration" which to-day leads to the probing into the depths of the sea, and even the polar extremities.

The twenty-one chapters are built around one (or more) outstanding men who added something fundamental to the science; the provocative titles give only a hint of the contents, for example: Chapter I—Fluids and Exhalations (Aristotle, Strabo, Pliny); Chapter IV—Geology by Dictum (Werner); Chapter VII—Like Goes with Like (William Smith); Chapter XIII—Geologist at Large (James Hall); Chapter XV—That a Nation Might Grow (William E. Logan); Chapter XIX—Canyons Conqueror (John Wesley Powell); Chapter XXI—Glaciers to Galaxies (Thomas C. Chamberlin).

Throughout the book the practical applications of the new geologic principles that were evolved are stressed and the authors conclude that, "These triumphs [of geology] have given human beings a new and improved world outlook; they have added to our joy

[1] Manuscript received, August 27, 1945.

in the world; they have helped us build up stores of knowledge with which we make use of the earth and improve our lot upon it."

This is a book which every geologist will enjoy reading, regardless of his specialty. All can, I believe, agree with the authors that "we owe our way of living if not life itself to the men who achieved this [geologic] revolution."

STRATIGRAPHY OF THE MARMATON GROUP, PENNSYLVANIAN, IN KANSAS, BY JOHN MARK JEWETT

REVIEW BY W. C. IMBT[1]
Wichita, Kansas

"Stratigraphy of the Marmaton Group, Pennsylvanian, in Kansas," by John Mark Jewett. *State Geol. Survey Kansas Bull. 58*, University of Kansas, Lawrence (1945). 148 pp., 4 pls.

This bulletin accomplishes the detailed description of the Marmaton group of Pennsylvanian rocks underlain by the Cherokee and separated from the overlying Missourian series by a regional unconformity. Several years of surface study in southeastern Kansas, southwestern Missouri, and northeastern Oklahoma form the basis for the very complete treatment of the geology of the Marmaton group of beds with which this bulletin deals.

The Marmaton group includes eight recognized limestone and shale formations which are subdivided into designated member units. Each formation and member is described in considerable detail regarding its geopgrahical distribution and lithologic characteristics. There are 203 detailed descriptions of stratigraphic sections, of which 179 are from southeastern Kansas, 7 in southwestern Missouri, and 17 from northeastern Oklahoma. Important fossils are mentioned, but no attempt is made to make complete faunal or floral tabulations or descriptions of specific fossils. Included are four correlated outcrop sections which effectively show variations of lithology and thickness of the formation units of the Marmaton group.

A section of the bulletin is devoted to the application of the general concepts of cyclic sedimentation to the Marmaton group of rocks. Four megacyclothems are recognized: (1) the Fort Scott, (2) the Pawnee, (3) the Altamont, and (4) the Lenapah. Each megacyclothem and its component cyclothem are described in considerable detail.

The treatment of the stratigraphy of the Marmaton group in Kansas should be of great assistance to those interested in surface stratigraphy and structure in southeastern Kansas. Its application to subsurface conditions in central and western Kansas is not beyond the scope of the report.

[1] Stanolind Oil and Gas Company. Review received, August 23, 1945.

RECENT PUBLICATIONS

ALASKA

"Geology and Oil Possibilities of the Southwestern Part of the Wide Bay Anticline, Alaska," by L. B. Kellum, S. N. Daviess, and C. M. Swinney. *U. S. Geol. Survey* (September, 1945). A geologic map on the scale of 1 inch equals 4,000 feet. Mimeographed report of 17 pages contains fossil plates and measured sections. May be purchased from Director, Geological Survey, Washington 25, D. C. Price, $0.60.

*"Drilling in Alaska," by Bart W. Gillespie, as told to William A. Coblentz. *Oil Weekly*, Vol. 119, No. 1 (September 3, 1945), pp. 54–56; illus.

ALBERTA

*"Alberta Gas Resources," by Floyd K. Beach. *Oil Weekly*, Vol. 119, No. 3 (September 17, 1945), pp. 47–50; 1 map, 1 table.

ARGENTINA

*"Antecedentes y perspectivas futuras de nuestra exploración petrolifera" (Past and Future of Our Petroleum Exploration), by Andrés Rozlosnik. *Y.P.F. Bol. Inform. Petrol.*, Vol. 22, No. 250 (Secretaria de Industria y Comercio, Buenos Aires, June, 1945), pp. 3–19; 8 figs.

BRAZIL

*"Brazil Has Four Oil Fields with 25 Producing Wells," by Avelino Ignacio de Oliveira. *World Petroleum*, Vol. 16, No. 10 (New York, September, 1945), pp. 74–75, sketch map.

CANADIAN ROCKIES

*"Triassic Faunas in the Canadian Rockies," by P. S. Warren. *Amer. Jour. Sci.*, Vol. 243, No. 9 (New Haven, Connecticut, September, 1945), pp. 480–91; 1 fig.

COLORADO

*"Structure of the Red Creek Area, Fremont County, Colorado," by A. R. Glockzin and Chalmer J. Roy. *Bull. Geol. Soc. America*, Vol. 56, No. 8 (New York, August, 1945). pp. 819–28; 1 pl., 1 fig.

GENERAL

*"Conservation of the Nation's Natural Gas Reserves," by Alex M. Crowell. *Petrol. Eng.*, Vol. 16, No. 12 (Dallas, Texas, August, 1945), pp. 164–70; 2 tables.

Illustrated Catalogue of North American Devonian Fossils. Section 9C "Thlipsuridae," by A. S. Warthin, Jr. 84 illus. cards. Wagner Free Institute of Science, Philadelphia 21, Pennsylvania (June, 1945). Price, $6.00, plus carriage.

*"Theory of Diastrophic Movement," by R. C. Tuttle. *Oil Weekly*, Vol. 119, No. 1 (Houston, September 3, 1945), pp. 42–45; 5 figs.

*"Planning Foreign Geophysical Parties," by C. H. Dresbach. *Oil Weekly*, Vol. 119, No. 3 (September 17, 1945), pp. 60–66; illus.

KANSAS-OKLAHOMA-TEXAS

*"The Hugoton Gas Field," by E. G. Dahlgren. *Petrol. Eng.*, Vol. 16, No. 12 (Dallas, Texas, August, 1945), pp. 178–86, map, table.

MICHIGAN

"The Salina and Bass Island Rocks in the Michigan Basin," by Kenneth K. Landes. *U. S. Geol. Survey Prelim. Map 40*, Oil and Gas Investig. Ser. (September, 1945). Sheet, 31×46 inches. Contains thickness maps, graphic, stratigraphic sections, structure maps, brief text. May be purchased from Director, Geological Survey, Washington 25, D. C., and from Geological Survey Division, State Dept. of Conservation, Lansing 13, Michigan. Price, $0.35.

"Lithology and Thickness of the Dundee Formation and the Rogers City Limestone in the Michigan Basin," by George V. Cohee and Lloyd B. Underwood. *U. S. Geol. Survey Prelim. Map 38*, Oil and Gas Investig. Ser. (September, 1945). One sheet, 44×59 inches. Maps, sections, text. May be purchased from Director, Geological Survey, Washington 25, D. C.; Geological Survey Division, Lansing 13, Michigan, Price, $0.40.

MISSISSIPPI

*"Heidelberg—A Major Mississpipi Oil Field," by K. Marshall Fagin. *Petrol. Eng.*, Vol. 16, No. 12 (Dallas, Texas, August, 1945), pp. 66–74; table, development map, 3 photographs.

OHIO

*"Water Injection in the Chatham Field, Medina County, Ohio," by Richard B. Lyon and Jack Cashell. *Oil and Gas Jour.*, Vol. 44, No. 17 (Tulsa, September 1, 1945), pp. 58, 61–66; 4 figs., 11 tables.

OREGON

*"Pumice Beds at Summer Lake, Oregon," by Ira S. Allison. *Bull. Geol. Soc. America*, Vol. 56, No. 8 (New York, August, 1945), pp. 789–808; 3 pls., 4 figs.

PACIFIC ISLANDS

*"Decadent Coral Reef on Eniwetok Island, Marshall Group," by Harold T. Stearns. *Bull. Geol. Soc. America*, Vol. 56, No. 8 (New York, August, 1945), pp. 783–88; 2 pls., 3 figs.

*"Solution Effects on Elevated Limestone Terraces," by J. Edward Hoffmeister and Harry S. Ladd. *Ibid.*, pp. 809–18; 1 pl., 2 figs.

RUSSIA

*"Twenty-Five Years of Study of the Quaternary in the U.S.S.R.," by V. Gromov. *Amer. Jour. Sci.*, Vol. 243, No. 9 (New Haven, Connecticut, September, 1945), pp. 492–516.

SCOTLAND

**Scotland· A Wealthy Country*, by Archie Lamont. 64 pp. A scientist's survey of Scots resources. "Oil Shales," pp. 43–46. Paper cover, approx. $5\frac{1}{2} \times 8\frac{3}{4}$ inches. Published by Scottish Secretariat, Ltd., 28 Elmbank Crescent, Glasgow, C 2, Scotland (1945). Price, 1/–.

*"Migration of Beach Material in the Kyles of Bute and Loch Striven Area, Scotland, and in North Wales," by Archie Lamont. *Trans. Buteshire Nat. Hist. Soc.*, Vol. 13 (1945). 23 pp., 6 figs. Approx. $5\frac{1}{2} \times 8\frac{1}{4}$ inches. Printed by The Buteman, Ltd., Rothesay, Buteshire, Scotland.

SOUTH AMERICA

*"First Generalized Geologic Map of South America," by Victor Oppenheim. *Pan Amer. Inst. Min. Eng. and Geol., U. S. Sec., Tech. Paper 2* (50 Church Street, New York 7, N. Y., 1945). Text, 11 pp. Map, 20×28 inches, in colors, scale, 1:11,200,000. All in paper covers, 6×9 inches.

TEXAS

"Geology of Hueco Mountains, El Paso and Hudspeth Counties, Texas," by P. B. King, R. E. King, and J. B. McKnight. *U. S. Geol. Survey Prelim. Map 36*, Oil and Investig. Ser. (September, 1945). 2 sheets, 44×48 inches and 38×41 inches. Map scale, 1 inch equals 1 mile. Structure sections and structure contour map, graphic sections, and brief text. May be purchased from Director, Geological Survey, Washington 25, D. C.; Room 234, Federal Building, Tulsa, Oklahoma; Room 314, Boston Building, Denver, Colorado. Price, $0.75 per set.

UTAH

*"Nomenclature of Triassic Rocks in Northeastern Utah," by J. Stewart Williams. *Amer. Jour. Sci.*, Vol. 243, No. 9 (New Haven, Connecticut, September, 1945), pp. 473–79; 2 figs.

WYOMING

"Map of Wyoming, Showing Test Wells for Oil and Gas, Anticlinal Axes, and Oil and Gas Fields." *U. S. Geol. Survey Prelim. Map 19* (Revised), Oil and Gas Investig. Ser. (September, 1945). Locations of 40 wells have been added to the approximately 1400 locations shown on the map as first printed. Scale, 1 inch equals 8 miles. May be purchased from Director, Geological Survey, Washington 25, D. C.; Federal Building, Casper, Wyoming; Room 314, Boston Building, Denver, Colorado; Room 234, Federal Building, Tulsa, Oklahoma. Price, $0.50.

"Stratigraphic Sections and Thickness Maps of Lower Cretaceous and Nonmarine Jurassic Rocks of Central Wyoming," by J. D. Love, Raymond M. Thompson, Chester O. Johnson, H. H. R. Sharkey, Harry A. Tourtelot, and A. D. Zapp. *U. S. Geol. Survey Prelim. Chart 13*, Oil and Gas Investig. Ser. (September, 1945). One sheet, 38×56 inches. May be purchased from Director. Geological Survey, Washington 25, D. C.; Federal Building, Casper, Wyoming; Boston Building, Denver, Colorado; Federal Building, Tulsa, Oklahoma. Price, $0.40.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

* *Journal of Paleontology* (Tulsa, Oklahoma), Vol. 19, No. 5 (September, 1945).

"Review of Latest Paleocene and Early Eocene Mammalian Faunas," by Franklyn B. Van Houten.

"New Upper Cambrian Trilobites from the Lévis Conglomerate," by Franco Rasetti.

"New Species of Brachiopods from the Devonian of Illinois and Missouri," by G. Arthur Cooper.

"A Belemnite from a Mississippian Boulder of the Caney Shale," by Rousseau H. Flower.

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"Some Silurian Trilobites from Port Daniel, Quebec," by Cecil H. Kindle.

"Pachycephalosauridae Proposed for Dome-Headed Dinosaurs, *Stegoceras lambei*, n. sp., Described," by C. M. Sternberg.

"A New Species of Selachian from the Lower Carboniferous of Canada," by C. M. Sternberg.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 10 (OCTOBER, 1945), PP. 1525-1529

THE ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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John Smith Bell, Tyler, Tex.
Olin G. Bell, C. I. Alexander, E. A. Wendlandt

Milton Charles Born, Stockton, Calif.
O. C. Lester, Jr., Downs McCloskey, B. B. Weatherby

William Ernest Denton, Bogota, Colombia, S. A.
J. Wyatt Durham, Geoffrey Barrow, J. Donald Macgregor

Leroy Gideon, Fort Worth, Tex.
Alton C. Allen, W. M. Winton, Hewlett A. Russell

Jack P. Hays, Dallas, Tex.
William W. Clawson, T. K. Knox, James A. Lewis
Floyd T. Johnston, Galveston, Tex.
Shepard W. Lowman, W. S. Adkins, Frank E. Lozo, Jr.
James Leo Minahan, Fort Worth, Tex.
Glenn R. V. Griffith, Ralph W. Richards, Thomas L. Coleman
Eduardo Ospina-Racines, Bogota, Colombia, S. A.
W. C. Hatfield, Paul H. Boots, John W. Butler, Jr.
Keith L. Rathbun, San Antonio, Tex.
J. Archer Culbertson, Malcolm D. Bennett, A. L. Jones
Clifford Harold Ritz, Matagorda, Tex.
C. H. Sample, R. L. Beckelhymer, A. P. Allison
Walter Blue Spangler, Richmond, Va.
Winthrop P. Haynes, Eugene Stebinger, K. D. White
Leonard Herman Thawley, Amarillo, Tex.
G. R. Elliott, W. B. Weeks, Max David
John W. Vanderwilt, Denver, Colo.
N. W. Bass, Henry Carter Rea, C. E. Dobbin
Lincoln Abraham Walker, Houston, Tex.
P. H. O'Bannon, H. J. McLellan, Olin G. Bell
Thomas Scott West, San Antonio, Tex.
A. H. Alcorn, H. E. Menger, William H. Spice, Jr.
John Bernard Woolly, Caracas, Venezuela, S. A.
Louis Kehrer, S. T. Waite, H. J. Fichter

FOR ASSOCIATE MEMBERSHIP

Anna Lou Bright, Austin, Tex.
K. H. Schilling, Hal P. Bybee, L. C. Snider
Ethel Margaret Davis, Wichita Falls, Tex.
Joseph H. Markley, Jr., Donald Kelly, H. Giddings
Eleanor Thompson Caldwell, Tallahassee, Fla.
W. S. Adkins, Shepard W. Lowman, Doris S. Malkin
Hugh P. Downey, Houston, Tex.
Hart Brown, Lewis H. Boyd, Harry L. Thomsen
Abner Lipscomb Foster, San Antonio, Tex.
Gilbert L. Brown, Martin Matson, Harold G. Picklesimer
Kenneth Stewart Fricke, Caracas, Venezuela, S. A.
W. S. Olson, Joe G. Wilson, J. M. Patterson
George Robert Gray, Houston, Tex.
F. W. Rolshausen, Paul Weaver, Olin G. Bell
John Craig Kammerer, University, Miss.
W. C. Morse, V. T. Stringfield, Glen F. Brown
Joel Joseph Lloyd, Bogota, Colombia, S. A.
Phillip Andrews, J. A. Tong, Harvey M. Lytel
Gilberto Garcia Morales, Oklahoma City, Okla.
A. J. Montgomery, D. E. Lounsbery, I. Curtis Hicks
William Edward Burckhardt Pappert, Maracaibo, Venezuela, S. A.
A. Allen Weymouth, G. Leslie Whipple, F. Walker Johnson
Frederick C. Porter, Bogota, Colombia, S. A.
W. E. Nygren, T. J. Newbill, C. H. Ramsden
Francis Archibald Roberts, Tulsa, Okla.
Harry M. Buchner, Paul L. Lyons, George E. Wagoner
Jack Pinknea Rodgers, Clarendon, Tex.
L. C. Snider, Hal P. Bybee, F. L. Whitney
Henry Stanley Taylor, Jr., Wichita, Kan.
Joseph R. Clair, F. E. Mettner, Wendell S. Johns

Richard Stanley Watson, Rolla, Mo.
Norman S. Hinchey, Garrett A. Muilenburg, Allen R. Ostrander
Robert McMaster Weidman, Bakersfield, Calif.
Ian Campbell, John P. Buwalda, Herman W. Weddle

FOR TRANSFER TO ACTIVE MEMBERSHIP

Burton Wallace Collins, Auckland, New Zealand
F. K. G. Mullerried, W. G. Argabrite, Harve Loomis
Albert Irwin Ingham, Tallahassee, Fla.
E. H. Rainwater, W. W. Rand, G. D. Thomas
Ludvig Carl Lindeblad, Midland, Tex.
Russell Farmer, Samuel P. Ellison, Jr., Charles F. Henderson
Ralph Nelson Thomas, Ashland, Ky.
Daniel J. Jones, Coleman D. Hunter, Paul Averitt

NEW YORK DISTRICT MEETING[1]

GAIL F. MOULTON[2]
New York, N. Y.

On September 5, thirty petroleum geologists of the New York area met for luncheon at the Harvard Club to greet MONROE G. CHENEY, president of the Association. Following the luncheon, President CHENEY gave an informal talk discussing current activities of the Association. He outlined the longer-range research projects now being considered, particularly those involving fundamental research into the sedimentary environment in which oil source material accumulates. The publication program was reviewed, and the interest of the Association in obtaining for use in the *Bulletin* additional papers on foreign areas was mentioned.

HENRY R. ALDRICH presented an informal statement regarding the matter of the "Institute of Geology" and in particular, the consensus of the Geological Society of America. He pointed out that the Geological Society was founded for the promotion of the science of geology in North America and that it alone of the prominent organizations of geologists in this country at the present time was in no way specialized as to the functions of the science with which it is concerned. The widespread field of interest of members of this organization, consequently, qualifies it for a leading role in any desirable advance of the fundamental thought behind the projected "Institute of Geology."

G. M. KNEBEL briefly discussed the research program of the American Petroleum Institute which is concerned with petroleum source sediments and sedimentary processes. His report was concerned with the desirability of coring and testing sediments which have accumulated off the coast of California as a contribution to fundamental data on the origin and accumulation of oil.

JOHN M. LOVEJOY concluded the informal remarks from the local members by a discussion of the hearings of the O'Mahoney Committee held in Washington during the past spring and summer in which he stressed the interest of many government departments in industry's attitude regarding the adequacy of oil resources within the United States. He commented in particular on the interest of the State Department in the possibility of finding oil generally over the world in various continental-shelf areas to a water depth of 100 fathoms, or less.

One item of interest to geologists in the New York area was the discussion following the adjournment of the meeting regarding the question of the formation of a more formal organization in the area which would schedule meetings and plan to take up various research programs as well as to hear addresses by distinguished lecturers and others having papers of unusual interest.

[1] Manuscript received, September 10, 1945.

[2] Association representative, New York district.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 10 (OCTOBER, 1945), P. 1530

MEMORIAL

LINN MARKLEY FARISH
DISTINGUISHED SERVICE CROSS[1]

On Thursday, August 30, in Charlottetown, Prince Edward Island, Canada, Mrs. Linn M. Parish was presented with the Distinguished Service Cross awarded to her late husband, Major Linn M. Farish, the presentation being made by Colonel S. S. Haddon of the United States Army in company with officers of the Canadian Army and Canadian Government officials.

A copy of the citation follows.

CITATION AWARD OF DISTINGUISHED SERVICE CROSS (POSTHUMOUS)

By direction of the President, under the provisions of Army Regulations 600-45, as amended, the Distinguished Service Cross was posthumously awarded by the Theatre Commander to the following named officer:

LINN M. FARISH, 0884213, Major, AUS, office of Strategic Services, Company B, 2677th Regiment, Office of Strategic Services, for extraordinary heroism in connection with secret military operations in the Balkans against an armed enemy during the period from 16 April to 16 June, 1944. Major Farish's descent by parachute into enemy occupied territory, his leadership, and his resolute conduct in the face of great peril, throughout an extended period, in the successful accomplishment of an extremely hazardous and difficult mission, exemplified the finest traditions of the armed forces of the United States. In a later hazardous assignment of vital importance to subsequent military operations, Major Farish was killed when his aircraft crashed during the course of operations.

By command of Lieutenant General McNarney.

GEORGE D. PENCE
Brigadier General, GSC,
Chief of Staff

[1] A biography of Linn Markley Farish was published in the *Bulletin*, Vol. 28, No. 12 (December, 1944), pp. 1783–85.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 10 (OCTOBER, 1945), PP. 1531-1536

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

FOR AVAILABLE GEOLOGISTS

The Association invites oil companies and other employers who desire the services of geologists to list their needs with

A.A.P.G. HEADQUARTERS
BOX 979, TULSA 1, OKLAHOMA

The executive committee desires to remind the members and associates that the Association offers the facilities of the Headquarters office to those seeking employment. The committee desires in particular to offer its services to those who have served in the Armed Forces and are now released and seeking employment. File a complete record of your education and experience with J. P. D. Hull, business manager, Box 979, Tulsa, Oklahoma. He will bring your qualifications to the attention of those who have filed their needs with his office. A member of the national service committee will be available for counsel.

FOR EDUCATIONS INTERRUPTED BY WAR
PREDOCTORAL FELLOWSHIPS IN NATURAL SCIENCES

The National Research Council announces that it is now ready to receive nominations and applications for the predoctoral fellowships in the natural (mathematical, physical, and biological) sciences which it is administering under a grant from the Rockefeller Foundation. These fellowships are intended to assist young men and women, whose graduate study has been prevented or interrupted by the war, to complete their work for the doctorate. It is hoped that these fellowships will do much to accelerate the recovery of the scientific vigor and competence of the country which is so seriously threatened by the loss of almost two graduate school generations of scientifically trained men and women.

This program will be administered by a Committee on Predoctoral Fellowships of the National Research Council whose members are Henry A. Barton, Charles W. Bray, Detlev W. Bronk, Luther P. Eisenhart, Ross G. Harrison (chairman—National Research Council, *ex officio*), W. A. Noyes, Jr., and John T. Tate, chairman; Enid Hannaford, secretary.

The annual stipend will be $1200 for single persons and $1800 for married men. In general it is expected that each recipient will spend at least eleven months per year on academic work. An additional allowance up to $500 per year will be made for tuition and fees. Fellowships granted to individuals who are eligible for educational support from the "G.I. Bill of Rights" will be at such stipends as to bring the total income from these two sources to that which would be received at the above rates.

Each fellow, before entering on his graduate studies, will submit for review by the Committee on Predoctoral Fellowships a schedule, approved by the dean of his graduate school, for the completion of his work for the doctorate. This schedule, as approved by the committee, will constitute an informal agreement upon the basis of which stipend payments will be made. At the discretion of the university concerned the fellowship stipend may be supplemented by university grants. All such supplementary sources of income should be made a matter of record with the committee. The progress of the fellows will be subject to periodic review by the committee which reserves the right to cancel fellowships when in their judgment satisfactory progress is not being maintained.

Prospective candidates for these fellowships are urged to apply at once even though they may be unable to undertake their graduate study in the immediate future. Information concerning these fellowships and Nomination-Application blanks are being mailed out widely to graduate schools and wartime research laboratories. They may also be obtained by writing directly to the Secretary, Committee on Predoctoral Fellowships, National Research Council, 2101 Constitution Avenue N.W., Washington 25, D. C.

IN HONOR OF E. H. SELLARDS

The Dallas Petroleum Geologists, HENRY C. CORTES, president, passed the following resolution upon the occasion of the retirement of E. H. SELLARDS, director of the University of Texas Bureau of Economic Geology. Similar resolutions have been adopted by the East Texas Geological Society and other geological societies.

Whereas, Dr. E. H. Sellards, Director, Bureau of Economic Geology, University of Texas, has passed his seventieth birthday, and in accordance with University regulations was relieved of administrative duties, September 1, 1945, to enable him to continue, uninterruptedly, his work in the field of research, and

Whereas, Dr. Sellards has spent many years of his life with the Bureau of Economic Geology, first as Geologist (1918 to 1927), and as Associate Director (1927 to 1932), and then as Director (1932 to 1945), investigating the occurrence and development of mineral resources in the State of Texas, and

Whereas, Dr. Sellards conducted geologic studies with a high degree of excellence, and freely disseminated the results of his investigations, and

Whereas, The Geology of Texas, Volumes I and II, regarded as a significant milestone in the progress of the Bureau of Economic Geology, as well as numerous other treatises and maps prepared under Dr. Sellards' direction, are used widely and beneficially by geologists, students, and laymen, and

Whereas, Dr. Sellards' unsullied professional and personal conduct has won the esteem and admiration of all persons with whom he has associated, therefore

Be It Resolved: That as a result of his protracted and unselfish efforts in advancing the science of geology, and assisting practicing and academic geologists, by contributing a fund of technical information that otherwise would not have been available, the Dallas Petroleum Geologists society, hereby, acknowledges a debt to Dr. E. H. Sellards, retiring Director, Bureau of Economic Geology, University of Texas, and asks that its appreciation and deep gratitude be accepted in part payment thereof.

Resolution passed unanimously at regular business meeting of the Dallas Petroleum Geologists, September 11, 1945.

Lieutenant Colonel MICHEL T. HALBOUTY, Infantry, AUS, former Houston consulting geologist and petroleum engineer, has been released from active duty and has reverted to inactive status with the same rank in the Army Reserves. Colonel Halbouty is a graduate of Texas A. & M. College and originally received his Second Lieutenant's commission

in the Army Reserves upon graduating from the College in 1930. He was called to active duty in February, 1942, at which time he held the rank of Captain. He was sent to Fort Benning, Georgia, where he graduated from the Battalion Commanders and Staff Officers Course. He then served at Fort Benning as an instructor in military tactics for 14 months. Later he was transferred to Washington where he was assigned as chief of the Petroleum Production Section, Planning Division, in the Army-Navy Petroleum Board under the Joint Chiefs of Staff. He served under Brigadier General Walter B. Pyron, former executive vice-president of the Gulf Oil Corporation in Houston, and Rear Admiral A. F. Carter, former president of the Progress Oil Company, Houston, Texas. Colonel Halbouty is resuming his consulting practice in geology and petroleum engineering, with offices and headquarters in the Shell Building, Houston, and subsidiary offices in New Orleans, Louisiana, and Louisville, Kentucky.

Robert E. King is in the employ of The Texas Company at New Orleans, Louisiana.

Major J. N. Gregory is resuming his practice as consulting geologist, after receiving his discharge from the Air Corps. His address is Box 243, San Angelo, Texas.

W. A. Waldschmidt is with the Argo Oil Corporation at Midland, Texas.

George N. May has resigned as geologist and paleontologist with the Union Sulphur Company to enter the consulting business with H. E. McGlasson at 208 Old Calcasieu Bank Building, Lake Charles, Louisiana.

O. A. Seager, now with the Standard Oil Company of Egypt, Cairo, is working on the Sinai Peninsula, in a region rich in Biblical history and across which Lord Allenby campaigned in 1914–1916.

R. G. Sohlberg, of the Richmond Exploration Company, is now located at Tienda Honda a Puente 61, Caracas, Venezuela.

Ray E. Morgan is regional geologist for the Socony-Vacuum Oil Company in charge of geological activities in the Central Magdalena Valley. His company address is Compania de Petroleos del Valle del Magdalena, Carrera 17, No. 35-76, Bucaramanga, Colombia, S. A.

Charles A. Steen is with the Socony-Vacuum Oil Company. His address is Box 1717, Lima, Peru.

Walter Franklin Pond, State geologist of Tennessee since 1927, has resigned. He is succeeded by H. B. Burwell. The office of the Division of Geology of the State Department of Conservation is at Nashville.

The Pacific Section of the Association has had an active study group which has met fortnightly throughout the summer, under the chairmanship of Martin Van Couvering. Each meeting has followed the program pattern of presenting one major paper and several minor discussions or reviews. Thus two score papers have been given during the summer, principally on stratigraphy and related subjects. The attendance has averaged nearly 60 persons at each meeting.

Howard C. Pyle of Glendale, California, has been appointed vice-president of the Bank of America in charge of the institution's new oil division. Pyle left the Union Oil Company of California in January, 1943, to enter the United States Army as petroleum engineer with the rank of captain, in the Washington, D. C., office of the chief engineer. He was promoted to Chief of the Oil Supply Rehabilitation and Development Branch of the Quartermaster General's office, with the rank of Major. In January, 1944, he was as-

signed to the general staff of Supreme Commander Eisenhower in the European Theater of Operations as petroleum officer. During the latter part of the pre-invasion planning and during the period Field Marshal Montgomery commanded all Normandy invasion troops Pyle was loaned by General Eisenhower to serve on Montgomery's general staff. In October, 1944, he was promoted to the rank of Lieutenant Colonel and from then on served as deputy chief of the general staff Oil Branch, Communications Zone. In this capacity he assisted in directing the petroleum supply to American Armies and Air Forces in Europe, including construction and operation of the now famous pipe lines across Europe.

D. T. LAWHORN has resigned as party chief for Geophysical Service, Inc., to accept the position of geophysicist with the Pan American Production Company at Houston, Texas.

CLARENCE M. SALE is instructor in mathematics and drawing at the Dallas Aviation School, Dallas, Texas.

ROBERT J. MINTON is with the Wasatch Oil Refining Company, Salt Lake City, Utah.

RUSSELL M. JEFFORDS, of Morgantown, West Virginia, is the author of *West Virginia Geological Survey Bulletin 10*, "Ground-Water Conditions along the Ohio Valley at Parkersburg, West Virginia," prepared in cooperation with the United States Geological Survey.

JAMES H. C. MARTENS, mineralogist, of the University of West Virginia, Morgantown, is the author of *West Virginia Geological Survey Bulletin 9*, "Fifty Common Rocks and Minerals of West Virginia."

CARL WIEDENMAYER may be addressed at 48 Blumenstrasse, Frauenfeld, Switzerland.

GLENN G. BARTLE, formerly professor of geology and dean of liberal arts at the University of Kansas City, has been released from the Navy and has joined the staff of E. Holley Poe and Associates, Utilities Consultants, of 70 Pine Street, New York. Bartle's Navy assignment included more than 2 years as commanding officer of the V-12 Unit at Swarthmore College, Swarthmore, Pennsylvania. He will continue to maintain his home in Swarthmore.

FRANK E. BROWN has resigned his position as district seismologist for the Shell Oil Company, Inc., and together with FRANK B. SMITH and A. V. DAYTON has organized Republic Exploration Company to conduct seismograph contracting and consulting work.

GEORGE F. BAUER, JR., chief petty officer in the United States Navy Seabees left the Philippines last August and was commissioned in San Francisco as an Ensign, retroactive to March, 1945. While in the Philippines, he was connected with the Engineering and Survey Section of the Seabee Brigade Headquarters. He has reported to the Graduate School of Business Administration, Harvard University, Boston, to be associated with the Navy Material Redistribution and Supplies Property Disposal Administration. Bauer is on military leave from the Stanolind Oil and Gas exploration department, Tulsa, Oklahoma, and Casper, Wyoming.

DONALD K. MACKAY has resigned his position with the Petroleum Division of the Foreign Economic Administration in Washington, D. C., and is currently employed as geologist by the Arkansas Oil and Gas Commission, 411 First National Bank Building, El Dorado, Arkansas.

DAVID M. GRUBBS, of the Danciger Oil and Refining Company, Fort Worth, Texas, presented a paper on "The Mississippi Salt Basin," at the meeting of the Shreveport Geological Society, Shreveport, Louisiana, on October 8.

Major PAUL H. PRICE, on leave as State geologist of the West Virginia Geological Survey, Morgantown, West Virginia, is looking forward to his early return to civilian life. Upon his arrival in Great Britain he was assigned to the British 21st Army Group as mineral specialist; landed in France with them during the invasion; came up across France with them and was their coal representative on the regional team in the Pas de Calais and Nord coal region. He was called back with SHAEF to head a coal team to go into the Saar coal field during its invasion; after the Saar was turned over to the French he was assigned to Production Control Branch USFET for coal and non-metallics. He may be addressed at G-5 Ind. Br. Hq. USFET (Main) APO 757, Postmaster, New York.

WILLIAM G. KANE, who has been chief of the Metals and Minerals Section of the Foreign Economic Administration in Mexico for the past 3 years, resigned from that post on September 1. The particularly satisfactory result of F.E.A.'s metals and minerals procurement program in Mexico suggested the advisability of the continuance of an active program to stimulate the development of new mineral resources there, particularly some of those in which the war has left U.S.A. with sharply depleted reserves. Kane has been retained as consulting geologist to the Bank of Mexico—Mexico's bank of issue—to assist in the evaluation, study, and development of such projects. His new work will cover the field of oil and gas, as well as metal and non-metallic mining. While his new offices will be at Room 504, Seguros de Mexico Building, 9 San Juan de Latran, Mexico D.F., his private post office address will continue to be Apartado 711, Mexico D.F.

PARKER D. TRASK, for many years with the United States Geological Survey at Washington, D. C., has now taken up his new duties as professor of geology at the University of Wisconsin, Madison.

NORMAN D. FITZGERALD, formerly director of the oil and gas division of the Great Lakes Carbon Corporation in New York City, has moved to Abilene, Texas. He is active there as an independent operator and consultant, doing geological work and drilling exploratory wells.

RALPH L. FILLMORE of the Anderson-Prichard Oil Company has resigned to join R. P. Sheets in a partnership to engage in the oil business. Their office is 1216 Petroleum Building, Oklahoma City.

ROY D. MCANINCH has resigned from his position with the Stanolind Oil and Gas Company at Oklahoma City.

Thirty five geologists attended a field trip sponsored by the Michigan Geological Society, September 14, 15, 16, into northern Ohio and the Bass Islands in Lake Erie. Outcrops of the Dundee limestone, the Detroit River group, and the Sylvania sandstone of Middle to Lower Devonian age, the Bass Island and Salina groups of Upper Silurian age, and upper Niagaran members of Middle Silurian age were examined in quarries of northern Ohio. The Columbus (Onondaga) limestone and upper Detroit River members were studied on the Bass Islands. An invitation to geologists in Ohio and New York to attend the trip was accepted by J. E. CARMAN and J. W. WELLS, Ohio State University; E. C. STUMM and F. FOREMAN, Oberlin College; W. H. SHIDELER, Miami University; H. F. KRIEGE, Holland, Ohio; and A. S. WARTHIN, JR., Vassar College. On Saturday night, the 14th, those attending the trip were guests of the Sun Oil Company at a dinner at Put-In-Bay. GEORGE R. SPENCER, supervisor, lease and land department, Toledo, Ohio, and geologists GEORGE LINDBERG, Toledo, Ohio, and GLENN SLEIGHT, Mt. Pleasant, Michigan, were the Sun Oil Company's representatives.

HUBERT GUYOD, well logging consultant, announces the opening of offices at 730 First National Bank Building, Houston, Texas. Guyod is the author of recent series of

articles on "Electrical Well Logging" and "Caliper Well Logging" which appeared last year and this year in the *Oil Weekly*.

LOYAL NELSON has resigned his position as geologist with The Texas Company of California, to enter private consulting practice in Los Angeles. His address is Room 220, Bartlett Building.

JACK L. HOUGH, formerly with the Humble Oil and Refining Company, Houston, Texas, after spending a year in the Navy Department, Washington, D. C., and two years with the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, has recently joined the Standard Oil Development Company as research geologist. His address is Room 2150, 30 Rockefeller Plaza, New York 20, N. Y.

Lieutenant Colonel J. A. EGAN, consulting geologist of Tulsa, Oklahoma, is in Germany, but expects to return to the United States this fall. He entered the services of the Air Force in June, 1942, went to England that year, participated in the operations and planning leading to the invasion and took part in the major campaigns on the continent.

H. N. FISK, of Louisiana State University, Baton Rouge, spoke on "Geological History of the Mississippi Alluvial Valley," at the first fall meeting of the Shreveport Geological Society, September 24.

Newly elected officers of the Shawnee Geological Society, at Shawnee, Oklahoma, are: President, RICHARD D. BUCK, Schlumberger Well Surveying Corporation; vice-president, DELBERT F. SMITH, Oklahoma Seismograph Company; secretary-treasurer, MARCELLE MOUSLEY, Atlantic Refining Company, Box 169, Shawnee.

The officers of the East Texas Geological Society are: president, GEORGE W. PIRTLE' of Hudnall and Pirtle, Peoples Bank Building; vice-president, F. B. STEIN, Tide Water Associated-Seaboard Oil Company; secretary-treasurer, T. H. SHELBY, JR., Humble Oil and Refining Company. Luncheons are held each week, Monday noon, at the Blackstone Hotel. Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

LOUIE C. KIRBY has resigned from the geological department of Stanolind Oil and Gas Company, Oklahoma City, Oklahoma, and may now be addressed at Geological Department, Tide Water-Associated Oil Company, Box 426, Tallahassee, Florida.

The 25th annual meeting of the American Petroleum Institute will be held at the Stevens Hotel, Chicago, November 12–15, 1945.

Because of continued hotel congestion, the Texas Mid-Continent Oil and Gas Association cancelled its membership meeting previously scheduled at Houston, Texas, October 4–6.

The Natural Gas Association of America plans to hold its convention at the Baker Hotel, Dallas, Texas, April 17–19, 1946.

The Pacific Section of the A.A.P.G., GLENN H. BOWES, president, and VINCENT W. VANDIVER, secretary-treasurer, will hold its annual meeting at the Ambassador Hotel, Los Angeles, on November 8 and 9.

President E. W. BERRY, of the Geological Society of America, died on September 19.

Major H. J. RUSSELL, JR., has returned to the Gulf Oil Corporation, Tulsa, after serving 34 months in England as Intelligence Officer in the Heavy Bomb Group.

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
DENVER, COLORADO

President - - - - - - - - - J. J. Zorichak
Petroleum Administration for War
First National Bank Building
1st Vice-President - - - - John Vanderwilt
Climax Molybdenum Company
2nd Vice-President - - - - Max L. Krueger
Union Oil Company of California
Secretary-Treasurer - - - - Robert McMillan
Frontier Refining Company
First National Bank Building

Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - - - Lee C. Lamar
Carter Oil Company, Box 568, Mattoon

Vice-President - - - - - - - - Jack Hirsch
The Texas Company, Mattoon

Secretary-Treasurer - - - - - Gene Gaddess
Pure Oil Company, Olney

Meetings will be announced.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY
EVANSVILLE, INDIANA

President - - - - - - - Stanley G. Elder
Sun Oil Company

Vice-President - - - - - Hillard W. Bodkin
The Superior Oil Company

Secretary-Treasurer - - - - - Jess H. Hengst
Barnsdall Oil Company

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - - - Virgil B. Cole
Gulf Oil Corporation
Vice-President - - - - - - - Laurence C. Hay
Consulting Geologist, 402 Union National Bank Building
Secretary-Treasurer - - - Edward A. Huffman
J. M. Huber Corporation, 407 First National Bank Building

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

President - - - - - - - - - Dean F. Metts
Humble Oil and Refining Company
1405 Canal Bldg.
Vice-President and Program Chm. - B. E. Bremer
The Texas Company, P.O. Box 252
Secretary-Treasurer - - - R. R. Copeland, Jr.
The California Company, 1818 Canal Bldg.

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President - - - - - - - - - T. H. Philpott
Carter Oil Company, Box 1739
Vice-President - - - - - Van D. Robinson
Atlantic Refining Company
Secretary-Treasurer - - - - - W. E. Wallace
Sohio Petroleum Corporation, Atlas Building

Meets the first Monday of every month, September to May, inclusive, 7:30 P.M., Criminal Court Room, Caddo Parish Court House. Special meetings and dinner meetings by announcement.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - Max Bornhauser
Continental Oil Co., Box 569, Lafayette
Vice-President - - - - - A. Lyndon Morrow
Magnolia Petroleum Co., Box 872
Secretary - - - - - - - Bruce M. Choate
Atlantic Refg. Co., Box 895
Treasurer - - - - - - - - P. F. Haberstick

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - Kenneth K. Landes
University of Michigan, Ann Arbor
Vice-President - - - - - - - - T. J. Weaver
Michigan Consolidated Gas Co., Grand Rapids
Secretary-Treasurer - - - Manley Osgood, Jr.
Cities Service Oil Co., Box 149, Mt. Pleasant
Business Manager - - - Harry J. Hardenberg
Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

President - - - - - - - - - - J. B. Storey
Union Producing Company

Vice-President - - - - - Frederic F. Mellen
Mellen & Monsour
Box 2571, W. Jackson Sta.

Secretary-Treasurer - - - - - J. B. Wheeler
Stanolind Oil and Gas Company

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - Stanford L. Rose
The California Company, 618 Simpson Bldg.

Vice-President - - - - - Maynard P. White
Gulf Oil Corporation, Box 30

Secretary-Treasurer - - Hamilton M. Johnson
Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - Ralph L. Fillmore
1216 Petroleum Building

Vice-President - - - - - Roy D. McAninch
Consulting

Secretary-Treasurer - - - - - Carl A. Moore
Carter Oil Company
1300 Apco Tower

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second Thursday, at 12:00 noon. Skirvin Hotel.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - - A. N. Murray
University of Tulsa
1st Vice-President - - - - Paul E. Fitzgerald
Dowell, Inc., Kennedy Building
2nd Vice-President - - - - - E. J. Handley
Shell Oil Company, Inc.
Secretary-Treasurer - - - Glenn R. V. Griffith
U. S. Geological Survey, Box 311
Editor - - - - - - - - Charles J. Deegan
Oil and Gas Journal, Box 1260

Meetings: First and third Mondays, each month, from October to May, inclusive at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Tuesday (October-May), Bradford Hotel.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - - - Richard D. Buck
Schlumberger Well Surveying Corporation

Vice-President - - - - - - - Delbert F. Smith
Oklahoma Seismograph Company

Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Companv, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TEXAS

DALLAS PETROLEUM GEOLOGISTS
DALLAS, TEXAS

President - - - - - - - - - Henry C. Cortes
Magnolia Petroleum Company
Vice-President - - - - - - - Cecil H. Green
Geophysical Service, Inc.
Secretary-Treasurer - - - - Willis G. Meyer
DeGolyer and MacNaughton, Continental Building
Executive Committee - - - Henry J. Morgan
Atlantic Refining Company

Meetings: Monthly luncheons by announcement. Special night meetings by announcement.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY
CORPUS CHRISTI, TEXAS

President - - - - - - - - - - - Ira H. Stein
Bridwell Oil Company, Alice, Texas

Vice-President - - - - Henry D. McCallum
Humble Oil and Refining Company

Secretary-Treasurer - - - - Elsie B. Chalupnik
Barnsdall Oil Company, 604 Driscoll Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - - George W. Pirtle
Hudnall & Pirtle, Peoples Bank Building
Vice-President - - - - - - - - - F. B. Stein
Tidewater Associated—Seaboard Oil Companies
Secretary-Treasurer - - - - T. H. Shelby, Jr.
Humble Oil and Refining Company

Luncheons: Each week, Monday noon, Blackstone Hotel.

Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

TEXAS

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - Thomas B. Romine
Sinclair Prairie Oil Company, 901 Fair Building

Vice-President - - - - - William J. Nolte
Stanolind Oil and Gas Company, Box 1410

Secretary-Treasurer - - - Spencer R. Normand
Independent Exploration Company
2210 Ft. Worth Natl. Bank Bldg.

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - William Lloyd Haseltine
Magnolia Petroleum Co., Box 239

Vice-President - - - - Charles R. Canfield
Stanolind Oil and Gas Company
909 Hamilton Building

Secretary-Treasurer - - - - John R. Davis
Superior Oil Company, 807 Hamilton Building

Luncheons and evening programs will be announced.

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - F. H. McGuigan
Lion Oil Refining Company

Vice-President - - - - - Leo R. Newfarmer
Shell Oil Company, Inc.

Secretary-Treasurer - - - - - Alan B. Leeper
Honolulu Oil Corporation

Meetings will be announced.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - W. B. Milton, Jr.
Houston Oil Co. of Texas, Box 2412

Vice-President - - - - - - - W. B. Moore
Atlantic Refining Company, Box 1346

Secretary - - - - - - - Charles H. Sample
J. M. Huber Corporation, 721 Bankers Mortgage Building

Treasurer - - - - - - - - Homer A. Noble
Magnolia Petroleum Company, Box 111

Regular meeting held the first and third Thursdays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO, TEXAS

President - - - - - - - - Harvey Whitaker
1409 Milam Building

Vice-President - - - - - - - George H. Coates
638 Milam Building

Secretary-Treasurer - - - - Marion J. Moore
Transwestern Oil Company, 1600 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

WYOMING

WYOMING GEOLOGICAL ASSOCIATION
CASPER, WYOMING
P. O. Box 545

President - - - - - - - - - C. J. Hares
The Ohio Oil Company

1st Vice-President - - - - - A. F. Barrett
General Petroleum Corporation

2nd Vice-President (Programs) - W. S. McCabe
Stanolind Oil & Gas Company

Secretary-Treasurer - - - - - R. M. Larsen
U. S. Geological Survey

Informal luncheon meetings every Friday, 12 noon, Townsend Hotel. Visiting geologists welcome. Special Meetings by announcement.

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P. O. Box 2605

President - - - - - - Douglas Rogers, Jr.
South Penn Natural Gas Company, Parkersburg

Vice-President - - - - - - Veleair C. Smith
Kanawha Valley Bank Building

Secretary-Treasurer - - - - W. B. Maxwell
United Fuel Gas Company, Box 1273

Editor - - - - - - - - H. J. Simmons, Jr.
Godfrey L. Cabot, Inc., Box 1473

Meetings: Second Monday, each month, except June July, and August, at 6:30 P.M., Kanawha Hotel.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - - - Henry C. Cortes
Magnolia Petroleum Co., Dallas, Texas

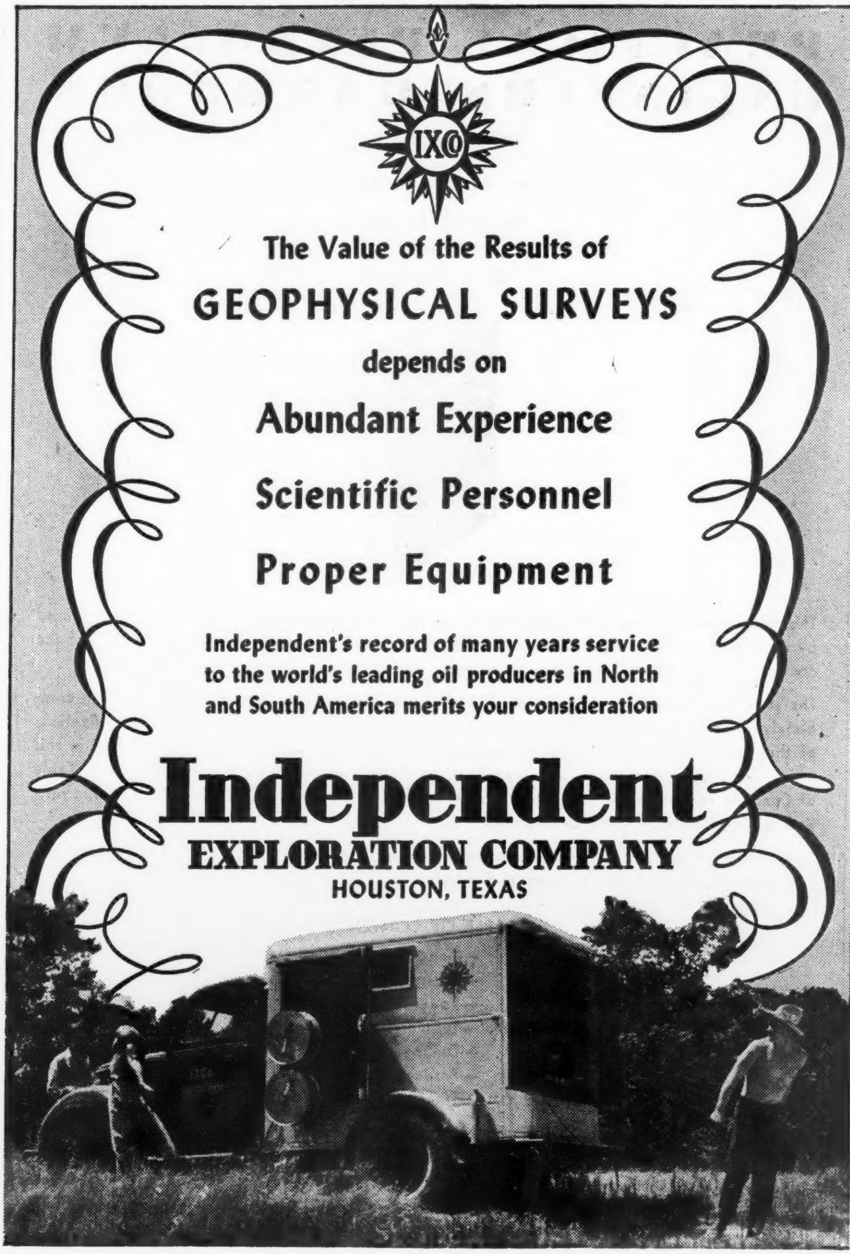
Vice-President - - - - - - - - J. J. Jakosky
University of Southern California, Los Angeles

Editor - - - - - - - - - - L. L. Nettleton
Gulf Research Laboratory, Pittsburgh, Pennsylvania

Secretary-Treasurer - - - - Cecil H. Green
Geophysical Service, Inc., 1311 Republic Bank Building, Dallas, Texas

Past-President - - - - William M. Rust, Jr.
Humble Oil & Refining Company, Houston

Business Manager - - - - - - - - E. Stiles
Hamilton, Texas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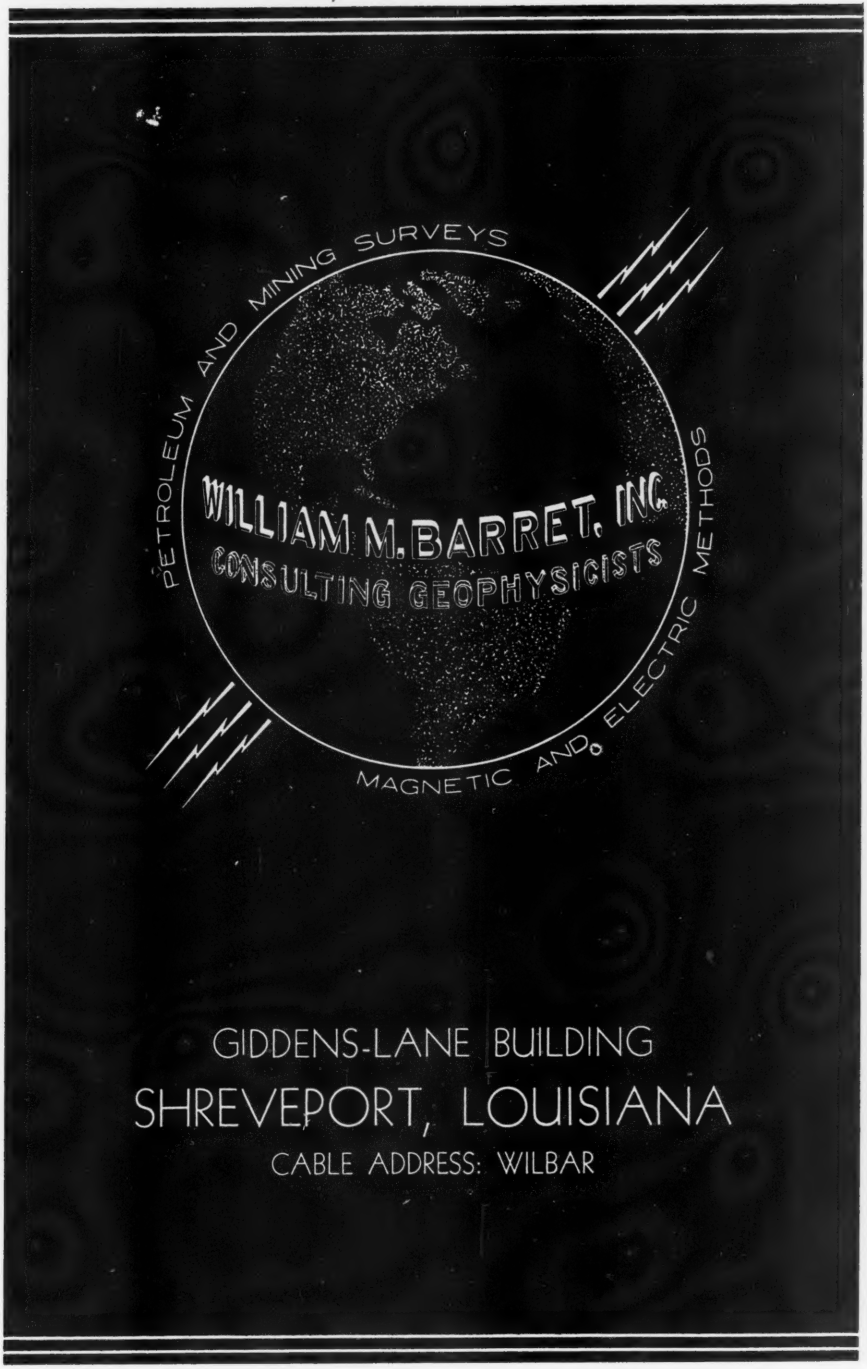
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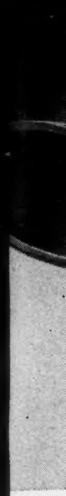

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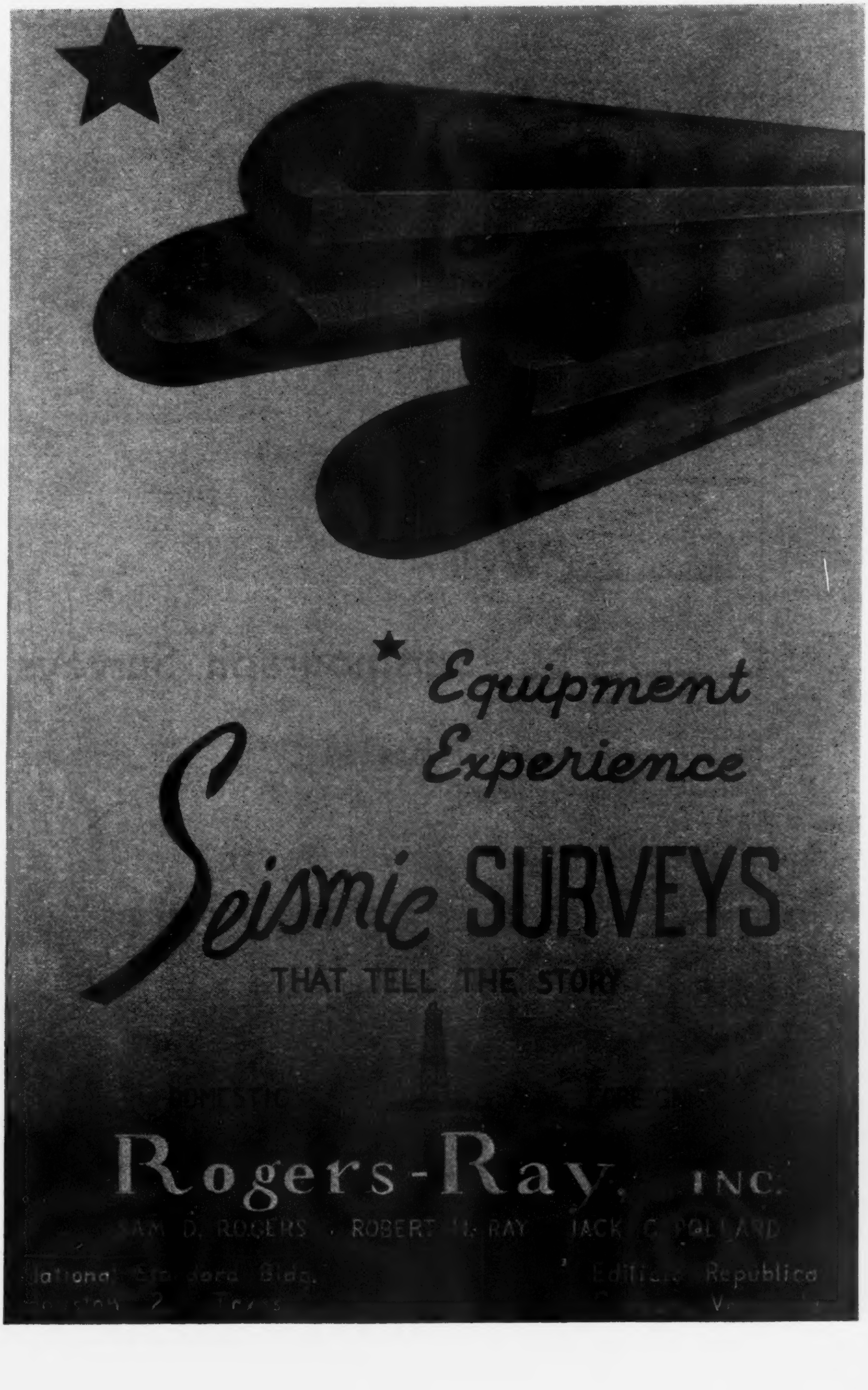
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